2.0 PROBLEMS ASSOCIATED WITH GROUND WATER EXTRACTION AND INJECTION SYSTEMS LEADING TO POOR PERFORMANCE OR UNACCEPTABLE RESULTS This chapter provides "trouble-shooting" tools to diagnose and find solutions for extraction, transport and injection units which are performing poorly. This Chapter provides tables which list problems, causes and solutions.

Many ground water extraction and injection system problems are due to oversights and errors in the RI/FS or design phases of the project. The identification and avoidance of serious design flaws is presented and discussed in Chapter 3.

2.1 Problems, Causes, and Solutions Problems with new and existing systems are identified by comparing system performance to the original system design analysis that describes what the system was intended to do and the initial system startup (baseline) data that indicate what the system was capable of doing when it first began operation.

Table 2-1 (located at the end of Chapter 2) identifies the primary symptoms/problems that have been observed with extraction, transport and injection units. Tables 2-2, 2-3, and 2-4 (located at the end of Chapter 2) are detailed trouble-shooting tables for extraction, transport, and injection units, respectively. The trouble-shooting process for extraction, transport and injection systems are illustrated, as Flowcharts, in Figures 2-2 through 2-10, also located at the end of Chapter 2. Note, "symptom" has not been defined as a specific system component failure, but rather as failure of the system to achieve an established objective. This approach allows the identification and consideration of more problems than the specific mechanical issues with which a system operator may be most familiar. The following sections expand on the topics presented in Table 2-1.

2.1.1 Extraction Unit The extraction unit can include extraction wells or trenches for the recovery of contaminated water and/or LNAPL. Table 2-2 is an extraction unit trouble-shooting chart, which describes the common symptoms, problems, problem descriptions, and solutions. References which provide detailed guidance are: Driscoll, 1986, USEPA OSWER Directive 9355.4-03, 1989, Helweg et al., 1983, Smith, 1995, U.S. Department of the Interior, Ground Water Manual, 1981, USEPA 600/R-94/123, 1994, Wisconsin Dept. of Natural Resources, PUBL-SW183-93, 1993, USEPA 510/R-96/001, 1996.

2.1.1.1 Low Water Production Rate A low water production rate is normally identified by comparison of actual production measurements to an expected rate that was established by pumping tests, modeling or during startup. Newly installed wells/trenches should be able to achieve the design analysis pumping rate at the time of commissioning.

Specific problems that may cause low initial water production rates are:

1) **Incomplete Characterization** of the site hydrogeology which may have resulted in inaccurate modeling of recovery systems during the design phase. Water production rate estimates are normally field verified by aquifer pumping tests which are performed prior to the design phase of the project. If modeling does not closely correlate with actual field aquifer pumping tests, the models should be reevaluated before any additional use.

For an existing extraction unit whose performance does not meet project objectives, evaluating the site characterization database using the checklist approach described in Chapter 3 may assist in identifying the required information that was not obtained during the design.

2) **Inappropriate Well Design Elements** which could result in inadequate production rates if improperly specified include: borehole diameter, filter pack sizing, well screen slot size, well screen material (e.g., stainless steel vs PVC), well screen area, well screen geometry and the location and length of the screened interval.

It is often difficult to effect performance of a poorly designed well by manipulating external factors such as pumps and level controllers. Therefore, solving an existing deficient well design frequently requires well replacement after determining the likely cause of well failure. Refer to Water Supply Sources and General Considerations (TM 5-813-1), U.S. Army Technical Manual, for information regarding water supply sources.

3) **Insufficient Well Development** may result in initial well production rates that are lower than the wells true capacity. This may be the result of ineffective or incomplete removal of drilling residue from the filter pack and the adjacent formation. This condition can be identified by confirming the presence of excessively turbid or high specific conductance in water, drilling fluid residues, or formation materials in the well.

Time limits should be established to ensure that mud rotary wells are not allowed to remain undeveloped for excessive lengths of time. Predevelopment takes place just after the filter pack is added to the annular space around the screen. The objective of predevelopment is to remove drilling fluids and natural fines which are still mobile and can settle the filter pack against the screen. Fines are much more easily removed at this time, which saves development time after full well completion. This will allow the filter pack to settle, thus allowing the additions of more filter pack before the bentonite seal is installed. Where possible, wells should be predeveloped by removing as much of the drilling fluids and muds during well installation. Failure to start development within reasonable time may cause problems with subsequent development, such as the need for more vigorous development procedures to remove drilling fluids and set the filter pack. In some cases, the well may not respond to development procedures and may result in the loss of the well. Subsequently, it may be necessary to properly redevelop the well with a procedure that will address the particular problems identified in the well. Poor development is a major contributing factor to biofouling problems in extraction and injection wells.

4) **Improper Pump Size** may result in low water production rates. This is often caused by inaccurately estimating the discharge head required to raise water from the well and push it through piping to the treatment unit. Under certain conditions, pumps capable of flow rates much greater than the discharge head requirement can also result in low well production rates due to excessive cycling, and their inability to develop and maintain a steady drawdown condition. In addition, oversized pumps cause mixing in the well and sometimes emulsification of LNAPL.

Pump size also plays an important role in mechanical reliability of equipment. Inadequate space between the pump and the well casing does not allow proper cooling of the pump motor and results in overheating and damage. The physical configuration of a pump must also be considered. As an example, an 18.4 cm (73 inch) outside diameter pump may fit inside a 20.3 cm (8 inch) inside diameter well and also meet discharge pressure requirements. However, the pump wiring is likely to be damaged during periodic maintenance removal and reinstallation due to abrasion with the well casing. Two ways to avoid pump wire damage is to ensure that pump wiring is affixed to the drop pipe of the well as pumps are installed into wells, and to ensure that there is sufficient annular space.

In order to prevent this problem specify the proper design parameters to select pumps that are capable of delivering the desired discharge head, provide flexibility in the range of flow rate control, and have adequate space for keeping the motor cool for better performance.

5) **Physical Damage/Blockage** to the well screen, pump inlet, or pump discharge piping may result in low water production rates. Pump problems are usually caused by careless installation and can be corrected by removing the pump from the well, inspecting the assembly for damage, and repairing as appropriate. Damage to the well screen is usually accompanied by the intrusion of filter pack and formation material into the well casing and is more difficult to repair. Generally the solution to well screen damage is the installation of a new well.

6) **Seasonal Aquifer Water Level Variation and Usage** may result in changes in production rates during periods of low precipitation.

7) **Incorrect Pump Control and Intake Settings** can result in lower than expected production rates if the low level control device (pressure switch, electrode or amperage meter) or pump intake is set at a shallow depth or low measurement threshold which shuts off the pump before the full available drawdown of the well has been achieved. This problem is detected by measuring well draw down at the pump shut off point and comparing it to the design expectation. This problem is rectified by lowering the pump intake to a greater depth or adjusting the low level control device to allow greater drawdown.

8) **Improper Construction** can affect water production rates. Contractor substitutions during construction can affect dynamics of the system and flow rates. Substitutions such as a slight reduction in pipe diameter or use of different fittings than those specified can affect system performance. All important system components should be installed exactly as shown and specified. Changes in system components should require a submittal to the design engineer.

2.1.1.2 Decrease in Production Rate Over Time A decrease in water production rates from extraction units may be observed over time by comparing current individual well production rates to baseline and previous performance records. Another useful measure of well productivity is specific capacity (gpm per foot of drawdown). This parameter should be measured during the baseline period and periodically during the operating period. Specific capacity or other performance criteria should be evaluated regularly and consistently. Specific guidelines should be written into the O&M plan to require notification to the lead agency that approved maintenance will be carried out. Production rate declines or decreases in specific capacity may be the result of the following problems:

1) **Mineral Encrustation** of well screens, pumps, impellers, level controllers, and piping is a common problem. Mineral encrustation problems can be addressed through a combination of preventative measures, routine inspection and maintenance. Encrustation consists of minerals which form with pressure drops, carbon dioxide off-gassing, aeration or other geochemical changes caused by pumpage, and shift equilibrium solubilities within the well/pump/piping system. This problem manifests itself as deposits that block well screen and pump inlets, plug discharge piping, and prevent the normal operation of level controllers. As the encrustation builds, production rates of wells drop off steadily. Trench extraction units are usually less sensitive to mineral encrustation because the pressure drop between the

formation and the inside of the sump is less severe, resulting in less carbonate formation.

Typical encrustation compounds include calcium and magnesium carbonates or sulfates, iron oxides, iron or magnesium hydroxides and sulfate salts which can vary from hard, brittle deposits to sludges or gelatinous materials. The solution to mineral encrustation problems is a combination of preventative measures and routine inspection and maintenance. The system should be designed to be as tolerant of scale buildup as possible by selecting durable well construction materials such as wire-wrapped, stainless steel well screen, pumps that do not have scale-sensitive moving parts or level controls, and equipment that can be easily removed and disassembled for cleaning. Also setting the intake of the pump above the screen minimizes the oxidation of iron and thus reduces biofouling of the screened area.

From a maintenance perspective, developing an effective well chemical treatment program based upon the system-specific water chemistry is critical. This program can be on a periodic schedule based on the rate of mineral build-up or a continuous-feed treatment system. Once the treatment process is established, routine treatment of wells followed by performance monitoring will identify any adjustments that may be required to optimize the treatment effectiveness. As part of maintenance, a chemical treatment program based on site-specific water chemistry may be necessary. Differences in water chemistry may be necessary. Differences in water chemistry between extracted (untreated) and treated water, as well as differences in water chemistry between individual wells may have to be taken into account to properly implement a chemical treatment program. Driscoll (1986) and Smith (1995) provide detailed guidance.

2) **Biological Fouling** results from the proliferation of microorganisms in the formation, filter pack or well screen. This proliferation is usually caused by the introduction of oxygen into the well (e.g. through over pumpage which drops the water level below the top of screen). However, fouling can also be caused by anaerobic bacteria metabolizing organic compounds. Biological fouling can be caused directly by the buildup of biomass or indirectly by the buildup of minerals formed as a byproduct of biological processes. Biologically facilitated mineral encrustation can include oxidation of iron, manganese and sulfur compounds. Hydrogen sulfide/sulfate reducing bacteria can promote corrosion of some well screens.

Generally, if the conditions are favorable, biological fouling is unavoidable. After a film of aerobic, bacterial growth has coated the inside of a well or pipe, anaerobic conditions may develop under the film. Anaerobic conditions under the film may then lead to accelerated corrosion of the wells and piping. Sulfate reducing bacteria are one group of anaerobic bacteria that can promote corrosion. However, preventative treatments can minimize fouling and systems can be designed to include materials that are resistant to treatment chemicals and include equipment that will function reliably with some degree of fouling. Regular, preventative well disinfection and prevention of overpumpage (which can aerate the formation) may delay the onset of biological fouling. Biological fouling which originates within a well can spread outward into the formation if preventative treatment is not performed. Once fouling has spread into the formation, rehabilitation to regain desired flow rates may be difficult, expensive or impossible.

As indicated above, mineral encrustation and biological fouling may occur simultaneously. Therefore, several treatment steps may be required. Biological treatments commonly include a step to eliminate microorganisms (e.g. application of a bactericide or bleach) followed by a step to break up and remove biomass and mineral encrustation (e.g. application of an organic acid). A sequestering agent and wetting agent may be used to help remove biomass and precipitants. In cases of severe fouling, several iterations of these two steps are frequently required to rehabilitate the well. Treatment chemicals should be carefully evaluated to verify that they do not contain compounds which could act as nutrients or facilitate further mineral formation if left behind at residual levels following treatment (e.g. nitrates or sulfates). Driscoll (1986) and Smith (1995) provide extensive guidance for prevention and treatment.

3) **Siltation** is the accumulation of excessive formation clays, silts and fine sands in wells or trench sumps. Siltation may be the result of inappropriately sized filter pack or well screen. Other possible causes of siltation include screen damage, improperly installed well joints, or improper development. Potential problems caused by siltation are reduced available screen capacity, plugging of pumps/piping, and excessive wear of pump impellers. Minor accumulation of silt is normal in a properly installed and developed well.

The most direct solution to siltation is to remove as much of the accumulated material as possible and redevelop the well. If siltation continues, a downhole camera should be used to identify damage to the screen and/or pipe joints, and document existing well conditions prior to beginning rehabilitation. If the well screen is damaged, other mechanisms may be required to reduce siltation. This may include insertion of a smaller diameter well screen and casing section into the damaged well. A second alternative is to raise the pump higher in the well where it will not be impacted by intruding silts. This approach may provide satisfactory results in those situations where the silt level within the well stabilizes over time.

High entrance velocity of water into the well adjacent to the pump intake is commonly the mechanism by which silt is mobilized. If there is available water column, raising the pump intake above the top of screen may reduce siltation by decreasing entrance velocities of water.

4) **Extended Periods of Dry Weather** may cause declines in water production rates from shallow water table systems due to lack of recharge. In these areas, thin saturated zones may depress to levels that do not permit cones of depression to intersect to capture all of the plume. During these periods, water levels drop, production rates decline and pump control settings may become inappropriate. In extreme droughts, water levels may fall below pump intakes or below the bottom of wells.

To avoid this problem, wells should be designed with sufficient screened interval to accommodate seasonal water level declines. In addition, O&M plans should include provisions for seasonal adjustments to the system to allow effective operation at the lower water levels. In prolonged droughts, wells may need to be deepened or replaced.

At a site having shallow water table aquifers where extraction is required, the designer should consider the use of shallow trenches, as their design addresses seasonal water fluctuations.

5) **Incompatible Pump Components** may result in decreasing production rates when chemical/physical conditions in ground water erode impellers, damage wiring insulation (resulting in short circuits) or cause leaks in air or water lines. This problem usually develops over a long period and is identified through a review of long term production rate trends and maintenance records. It is unusual to experience a dramatic system failure through incompatibility problems.

If this problem occurs, materials that are adversely impacted should be replaced with components that are compatible. If reduction in production rates is slow, routine replacement of inexpensive parts may be adequate. In order to avoid this potential problem, the designer should specify pumps designed for environmental operations. Most pump manufacturers have chemical compatibility charts to allow appropriate pump material specification.

6) **Well Interference** may result in reduced water production rates from wells spaced too close together and by seasonal water usage such as irrigation which may affect regional water levels. This may also cause excessive dewatering which reduces hydrocarbon recovery and can cause frequent cycling and damage to pumping equipment.

Ultimately this is a system design problem in that the wells may recover too much of the available water and the rates begin to drop off shortly after system startup. Solutions to this problem are to lower the pumping rates in individual wells to maintain a steady-state flow condition (particularly where hydrocarbon recovery is a concern), or to shut down recovery in alternating wells where the capture zones overlap. These solutions, however, may result in deficiencies for other system goals, such as plume capture.

2.1.1.3 Low LNAPL Removal Rates Ideally, LNAPL is independent of ground water recovery with maximization of LNAPL recovery and minimization of water removal.

Depending on site conditions, LNAPL recovery equipment may be quite different from more conventional ground water extraction equipment. In some cases both types of recovery equipment are required. In those instances, trouble-shooting low LNAPL removal rates becomes more complicated. API (1989) provides an excellent summary of LNAPL recovery methods and equipment. The following references provide detailed guidance: Abdul, A.S., 1992, Chiang, et al., 1990, Hampton and Heuvelhorst, 1990, Hayes et al., 1989, Testa and Paczkowski, 1989, Wilson and Conrad, 1984 and USEPA 510/R-96/001, 1996.

1) **Poor Site Characterization** can cause low LNAPL recovery, unsafe operating conditions and over/under estimation of recoverable LNAPL volumes.

Site characterization for design of LNAPL recovery systems must include measurement/estimation of the vertical/lateral extent of mobile LNAPL and residual LNAPL. The extent of residual LNAPL is controlled by the physical properties of LNAPL and soil, the rate of migration and seasonal water table fluctuations which smear LNAPL above and below the water table. Distinguishing between free flowing and residual LNAPL influences performance expectations, well placement, pump specifications, pumping strategies and screened intervals. Key measurements which are used to estimate LNAPL volumes and recoverable amounts include the following:

Detailed observations of soil staining in primary porosity and soil cracks/fissures during geological logging of soil samples: These qualitative observations are used to evaluate the primary pathway of LNAPL migration through soil. These findings influence assumptions made during estimation of recoverable LNAPL volumes.

Seasonal changes in LNAPL thicknesses and water levels in monitoring wells: These measurements are used to define the appropriate screened intervals for recovery wells and depth setting for pump/skimmer intakes.

Comparison of observed depth at which soils became saturated during drilling to depth of water level in well after development: This comparison allows estimation of the location of the capillary fringe upon which LNAPL can accumulate. This estimate is integral to correction of LNAPL thickness measurements from monitoring wells. This comparison is facilitated by measurement of soil moisture content and percent saturation in soil samples from above, at and below the water table.

Comprehensive chemical analyses of ground water constituents: Analyses of volatile and semi-volatile organic compounds performed by GC/MS will initially confirm constituents present, and help to identify appropriate, less expensive, analytical methods (e.g. SW-846 Method 8021), other GC analyses, and various petroleum hydrocarbon analyses to be used during mapping of the dissolved plume, and monitoring of remedial systems.

LNAPL specific gravity (ASTM D445 & D971): LNAPL specific gravity is used to correct water levels measured from wells which also contain LNAPL.

LNAPL interfacial tension and viscosity (ASTM D-88, D-4243, D87 and D2285): These measurements are used in calculations to estimate the total recoverable volumes of LNAPL.

Soil bulk dry density (ASTM D4564) and Soil moisture control (ASTM D2974): Soil bulk dry density is used to calculate total porosity, and in combination with soil moisture measurements from above the water table, to estimate effective porosity. These porosity estimates are used to calculate total and recoverable volumes of LNAPL.

Soil sieve analyses (ASTM D422): These measurements are used to estimate capillary fringe thicknesses, LNAPL volumes and to design well screen slot sizes.

Fraction of organic carbon in unimpacted soil (Page, 1986): These measurements are used in calculations to estimate the amount of dissolved compound sorption onto aquifer materials.

LNAPL baildown tests (Gruszczenski, 1987; and Hughes et. al, 1988): These tests (approximately analogous to a slug test for ground water) provide an empirical, qualitative measure of potential LNAPL recovery rates.

Estimating true versus apparent product thickness: Methods for estimating true product thickness on the basis of: a) apparent LNAPL thickness observed in monitoring wells, and b) fluid and porous media properties, have been developed by Lenhard and Parker et al.(1990) and Farr et al. (1990). These methods assume an equilibrium distribution of the three fluid phases (LNAPL, water and air) and require measurement (preferably) or estimation of capillary pressure-saturation curves for soils within the capillary fringe where most of the LNAPL typically resides. Due to spatial variability in subsurface properties, water table fluctuations, and other uncertainties, these methods may yield no better than order-of-magnitude estimates of mobile LNAPL distribution at some sites (USEPA 540/S-95/500, 1995).

2) **Poor Design** may cause low LNAPL recovery by not allowing extraction at appropriate locations, depths or rates. This can result from improper screen placement. As indicated in the previous section, the physical and chemical characteristics of the LNAPL must be understood to properly design systems. Poor design is difficult to address once the system is installed.

3) **Insufficient or Excessive Water Table Drawdown and Operator Error** may prevent adequate volumes of LNAPL from entering the extraction well or trench. Excessive drawdown may smear LNAPL vertically across dewatered soils and convert mobile LNAPL to a relatively immobile phase which is difficult to recover. In addition, excessive drawdown may be accompanied by high water production rates.

Drawdown can be controlled using dedicated water level controllers on electrical pumps or water level controlled pneumatic pumps. Selection of the most appropriate pump and control for this application must be evaluated in the design phase of the project.

4) **Weather and Tidal Influences** can cause the depth of the water table to vary widely over a matter of hours. This can consequently affect the depth of the mobile LNAPL. Recovery systems which are not designed to automatically adjust to changing conditions may experience high water recovery and low LNAPL recovery during high water periods and may run dry during low water periods. Common approaches to this problem include:

- verification of weather and tidal effects;
- use of pump or passive collection devices with intakes which float within the LNAPL layer;
- use of hydrophobic conveyor belts which preferentially collect LNAPL from any depth at which it might occur within the well;
- for sites which have significant water handling capabilities, placement of the pump intake at the seasonal low water table elevation, pumpage of all water and oil

together and separation of oil and water in the treatment system; and use of separate pumps for oil and water recovery to maintain water and fuel levels at predetermined depths by varying ground water productions rates.

2.1.1.4 <u>Excessive Water Production</u> Based upon the definition of a successful LNAPL recovery system as one which maximizes LNAPL recovery while minimizing ground water recovery, excess water production may be a significant indication of poor system performance.

Primary causes of excess water production are:

- inappropriate pump selection and control setting;
- extraction of LNAPL and ground water simultaneously;
- failure to adequately control drawdown of the extraction unit; and
- lowering of pumps or pump control sensors further down wells to provide operational convenience at the cost of remedial effectiveness.

2.1.1.5 <u>Inadequate Plume Capture</u> A ground water extraction unit may be considered unsuccessful if the system does not capture the extent of ground water standard exceedances. *Note: Some systems are designed to only capture a portion of ground water standard exceedances because the regulatory agency has approved natural attenuation for portions of the plume.*

Plume capture applies in this context to both LNAPL and dissolved phase contaminants. Inadequate well placement/spacing can cause insufficient capture. Inadequate plume capture can also result from unexpectedly low extraction flow. This failure is primarily the result of two factors, (1) wells or trenches that are spaced too far apart, and (2) not having thorough understanding of site heterogeneities which can cause inaccurate modeling. These heterogeneities can be sand/gravel lenses, rock fractures and gravel fill surrounding utility conduits. Ground water models are frequently used to predict the capture zone of a well system. Over-simplification or errors in the use of these models may result in the specification of inappropriate well spacings. Misuse of models may also result in over-prediction of sustainable pumping rates and therefore inappropriate specification of pump, transport, and treatment systems. Zheng et al. (1991) and USEPA 600/2-93/118 (1993) provide guidance regarding choice of models.

2.1.2 Transport Unit Table 2-2 is a transport unit trouble-shooting chart which describes the symptoms, problems, problem descriptions, and solutions for transport units. Flowchart 2-5 graphically identifies the problem identification process. The following is a discussion of the key issues.

1) **Poor Piping Design** may cause low injection rates if pumps and piping are undersized and incapable of transporting sufficient water for injection. This problem can be avoided in the design phase by appropriately sizing the discharge lines, accurately calculating pressure drops across the system and over-sizing pumps and piping to allow for some fouling (which increases back-pressure).

2) **Inaccurate Elevation Data** resulting from erroneous or low resolution topographic data can result in a miscalculation of heads.

3) **Weather Variations May Affect Transport Systems.** Cold weather may freeze exposed or inadequately covered lines and wellheads. Hot weather may cause excessive line expansion, shifting and line breakage. Long pipe runs should be equipped with expansion loops to allow for this movement.

4) **Fouling/Encrustation** of lines may result in injection system failure. Observation of encrustation or fouling at the extraction well may provide appropriate warning that some accumulation may be occurring within transport lines. Monitoring of pressures, periodic inspection and cleaning may be required to minimize the potential for this to develop into a significant problem. Cleaning can include use of pigs or snakes which are inserted at header lines to remove partial obstructions. The O&M plan should include procedures and schedules for these activities.

5) **Poor Maintenance** of transport lines may lead to failure by corrosion, excessive thermal expansion, mechanical vibration, or exposure to weather.

6) **Physical Damage** to shallow piping systems and aboveground components may be caused by automobile traffic, airplane traffic, or heavy equipment. The design should provide protective measures around aboveground components and provide sufficient load bearing capacity for subgrade components. In addition, all utility company and maintenance personnel should be provided with maps depicting the location of subgrade components to prevent damage during unrelated excavation work. Many systems include signs indicating locations of buried piping. Access to the system by well workover equipment and maintenance vehicles will be required at some point and should be accounted for in the design.

7) **Sedimentation**, as with the fouling, may cause line plugging, treatment system damage and plugging of injection wells. Sediment traps and adequate cleanout mechanisms in the piping system will facilitate the removal of accumulated sediments.

8) **Construction Debris** that is inadvertently trapped in the piping system may lead to line plugging. Soil, rust scale, pipe thread tape, and welding slag are all common materials which find their way into systems during construction. The most effective approach to this problem is to employ an inspection process during construction. Prior to final piping fit up, the piping should be flushed with water to remove debris. Temporary screens are commonly installed in suction lines of pumps during startup.

9) **Incompatible Materials** may cause line failure. Hydrocarbons/ chemicals that are incompatible with some types of plastic pipe may result in the softening and collapse of pipes. Dissimilar metals that are placed in contact with each other may cause galvanic corrosion. Comparison of construction material compatibilities with chemicals at the site will minimize the potential for this problem.

10) **Improper Construction** or inadequate oversight practices may lead to decreased system performance. For example, piping runs that are installed unevenly can cause air to be trapped in lines. Also, low points missed during surveying or construction can trap sediments.

2.1.3 <u>Injection Unit</u> Recovered ground water is commonly treated and injected to improve flushing of contaminants, to allow addition of nutrients to promote biodegradation, or to provide a hydraulic barrier to contaminant migration. Contrary to common belief, injection is not the "reverse" of ground water extraction and sustainable ground water extraction rates are not a reliable indicator of sustainable injection rates. The major differences between extraction and injection are as follows:

1) Sustainable extraction rates are determined by the hydraulic conductivity and saturated thickness of the aquifer below the water table. Sustainable injection rates are determined by screen placement, the hydraulic conductivity and unsaturated thickness of materials between the water table and the ground surface.

2) Injection wells can sometimes be designed with larger slot openings than extraction wells because of less concern regarding siltation.

3) Well screens are exclusively designed to minimize head losses for water entering the well. Depending on the internal

geometry of the screen, injection wells may experience greater head losses than extraction wells.

4) The chemistry of injected water is often significantly different than that of the original ground water because of treatment steps, aeration and changes in temperature that occur after extraction.

5) Injection can occur under gravity feed or pressure feed conditions.

Table 2-3 is an injection system trouble-shooting chart which describes the symptoms, problems, problem descriptions, and solutions for injection systems. The following references provide guidance regarding ground water injection: Driscoll, USEPA OSWER Directive 9355.4-03, 1989, USEPA 600/2-79/170, 1979, USEPA 600/S8-87/013, 1987, USEPA 600/2-77/240, 1977, USEPA 625/R-94/003, 1994, and USEPA 600/S8-88/008, 1988.

2.1.3.1 Low Injection Rates Poor injection capacity is the inability of the well to allow the necessary flow rates back into the formation. Generally, it is more difficult to return ground water to the aquifer than to remove it. As a result, the injection system must be designed with excess capacity. This may include flexibility for conversion from gravity feed to pressurized injection.

Poor well design may result in low injection rates. Consideration must be made for the desired flow rate combined with the ability of the aquifer to accept the flow. This requires an adequate understanding of hydrogeologic conditions and factors listed in the previous section.

2.1.3.2 Injection Rates Falling Operational monitoring may reveal that injection rates are decreasing over time. Decreasing injection rates should prompt an evaluation of the following issues:

1) **Encrustation/Fouling/Precipitation** in the well screen or formation may lead to falling injection rates over time. This problem will likely be observed in injection wells first, because the area available for water to be injected is limited by the area of the surface of the bore hole. Both the screen and the filter pack in a properly designed well are so permeable as to provide little resistance when compared to the formation at the bore hole interface. Although a well in a one foot diameter boring would have a surface area of 3.14 square feet per foot of screen length, only a portion of that surface is pores. The ability to block off those pores with particles is inversely related to the diameter of the pores. Consequently, both fine grained and well graded formations have smaller pore throats and are more susceptible to clogging by suspended particles or gas

bubbles entrained in the water (see Figure 2-1). However, precipitation problems may also manifest themselves downstream of the treatment system due to changes in water chemistry. Changes in water chemistry may also affect the formation, causing changes to formation clays that cause the wells to become plugged. The following are problems with injection well clogging that are commonly limiting factors on the viability of the well:

- Calcium carbonate incrustation created by rising pH following treatment such as air stripping.
- Iron and manganese precipitation under oxidizing conditions.
- Sediment entrained in the injection water.
- Bacterial contamination.
- Chemical reactions between ground water and recharge water of different quality.
- Mechanical jamming caused by reversal of water movement in the vicinity of the well.
- Clay swelling and clay dispersal from injected water.
- Air entrainment in the recharge water.
- Viscosity changes from differences in water temperature between ground water and recharge water.

Refer to Olsthoorn 1982 for further detail on the fouling of recharge wells.

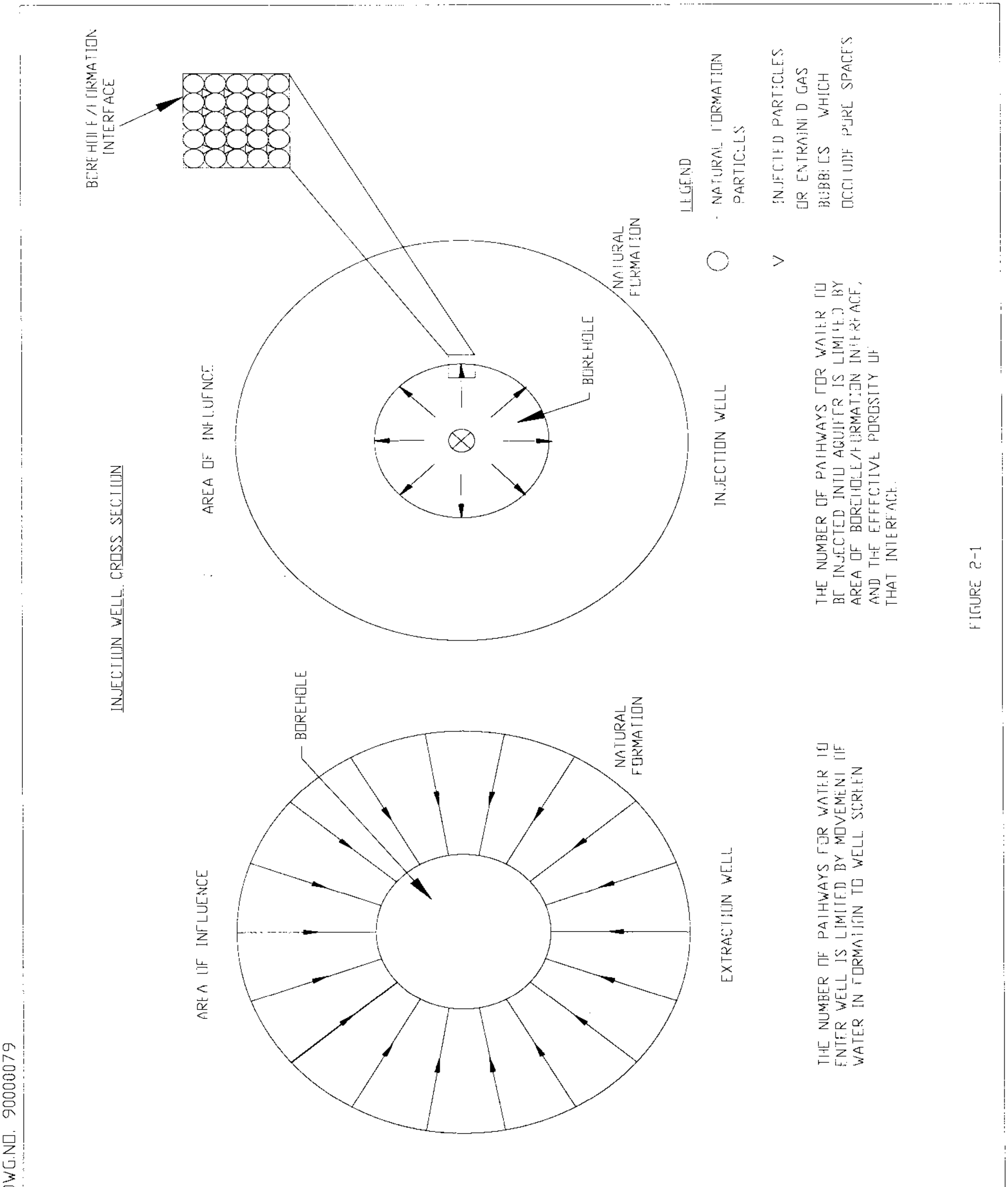
INJECTION WELL CROSS SECTION
BOREHOLE/FORMATION INTERFACE
AREA OF INFLUENCE
BOREHOLE
NATURAL FORMATION
INJECTION WELL
LEGEND
NATURAL FORMATION PARTICLES
INJECTED PARTICLES OR ENTRAINED GAS BUBBLES WHICH OCCLUDE PORE SPACES
THE NUMBER OF PATHWAYS FOR WATER TO BE INJECTED INTO AQUIFER IS LIMITED BY AREA OF BOREHOLE/FORMATION INTERFACE, AND THE EFFECTIVE POROSITY OF THAT INTERFACE.
AREA OF INFLUENCE
BOREHOLE
NATURAL FORMATION
EXTRACTION WELL
THE NUMBER OF PATHWAYS FOR WATER TO ENTER WELL IS LIMITED BY MOVEMENT OF WATER IN FORMATION TO WELL SCREEN
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FIGURE 2-1

Installation of de-aeration systems and pH adjustment systems can be used to minimize encrustation. In addition, silt traps can be used to remove solids conveyed from the extraction wells or which form in-line prior to entry into injection wells. Installation of drop pipes to ensure that water does not cascade into the well can also help to minimize formation of some minerals. The O&M plan should include periodic inspections of well screens via downhole camera and appropriate well redevelopment schedule to maximize injection rates. When trouble-shooting or designing injection systems, consider the advantages of injection trenches over injection wells. Injection trenches are easier and less expensive to install, and require less maintenance for optimum operation than injection wells.

2) **Nutrient and Dissolved Oxygen Interaction with the Aquifer** The addition of nutrients to the aquifer (during in-situ biotreatment) may result in biological growth in the formation around injection wells. Over time, this biological growth may block off the aquifer. Periodic or constant feed chemical treatment of the injected water to kill bacteria or retard their growth is one approach to this problem. However, this approach may be contrary to the objective of promoting biological treatment in the formation and may not be permitted by UIC rules or regulations.

3) **Improperly Constructed Injection** units may lead to decreased performance over time. A common error in design of pressure injection wells is the use of PVC riser pipe. Although the material may be rated to withstand injection pressures, slight contraction and expansion of the casing as injection pressures vary can result in failure of the grout seal. Failure of the grout seal results in short circuiting of injected water to the surface and inability to force water into the aquifer under pressure. Therefore, while it may be appropriate to use PVC in gravity-feed injection wells, it is rarely advisable to use PVC in the construction of pressure injection wells.

2.1.3.3 Plume Redirection Injection of ground water is often performed to flush the existing contaminant plume towards extraction wells. In some instances, injection may not successfully accomplish this objective. The following situations may lead to this failure:

1) **Injection Wells Improperly Located** due to site constraints, inadequate characterization or improper modeling may lead to misdirection of the plume. An adequate understanding of the hydraulics created by the desired injection program is critical in avoiding this problem. Injection testing is necessary to minimize the chances for this problem. The results of this testing should be used to calibrate ground water models constructed to choose well placement and specify water balances. In addition, potentiometric monitoring points should be installed

to gauge whether the desired result is being achieved and to aid in specification of operational adjustments.

2) **Incorrect Water Balance**, or poor understanding of where the system's water is coming from may lead to a shift in the contaminant plume. This situation may develop in shallow aquifers that are not continuous or vary in their capacity to produce and accept water across the project site. This problem is generally a result of the lack of adequate site characterization.

TABLE 2-1

Ground Water Extraction/Transport/Injection System Problems and Possible Causes

Extraction Unit	Surface Transport System	Injection System
1) LOW WATER PRODUCTION (Initial) Inadequate hydrogeologic characterization Improper well design Incorrect well installation/material selection Pump/pumping size Wrong pump type Improper pump control and intake settings Well location Improper well development	**1) TRANSPORT/PIPING PARTIAL/COMPLETE BLOCKAGE** Poor design and installation Weather Fouling/encrustation Poor maintenance Physical damage Sedimentation Construction debris Incompatible materials Air bubbles Air accumulation in high points Freezing Leaks due to improper installation	**1) LOW INJECTION RATES** Wrong well design Inadequate characterization Inadequate injection capacity Pump/piping design
2) LOW CONTAMINANT MASS REMOVAL Inadequate characterization Incorrect design; well/screen depth Improper pump type/size Too little/too much drawdown Tidal/weather fluctuations during NAPL recovery	**2. FREQUENT LINE RUPTURES** Poor Design Weather/UV Degradation/Corrosion Incompatible materials Pressure surges	**2) INJECTION RATES FALLING** Encrustation/precipitation Nutrient interaction with aquifer Dissolved oxygen interaction with aquifer Transport of air bubbles into aquifer Transport of suspended solids into aquifer Biological fouling/growth blocking well
3) PRODUCTION RATE FALLING Encrustation/fouling Well placement Siltation Pump impeller wear Weather; seasonal low water table Incompatible well screen		**3) PLUME REDIRECTION** Injection wells improperly located Inadequate characterization Water balance/injection balance

TABLE 2-1 (Cont'd)

Ground Water Extraction/Transport/Injection System Problems and Possible Causes

Extraction Unit	Surface Transport System	Injection System
4) EXCESS WATER PRODUCTION Pump size Inadequate characterization Improper design		**4) MOUNDING/FLOODING** Inadequate characterization/design Operational/problems Encrustation Sedimentation Construction debris Weather; seasonal high water table Incorrect pressure/level control settings Biological fouling/growth blocking well
5) INADEQUATE PLUME CAPTURE Improper design Pumps too small Pumps too large, excessive cycling Inadequate characterization/modeling Poor placement/spacing of wells Plume movement during construction delays		
6) HIGH CONTAMINANT LOADING Inadequate characterization/modeling Poor placement/spacing of well		

Note: Low, excess and inadequate trends are defined by comparison to performance criteria and baseline performance

TABLE 2-2

Extraction Unit Troubleshooting

Symptom	Problem	Description	Solution
Initial Water Production Lower than Design	Poor Characterization	Poor/incorrect characterization leading to inaccurate modeling and/or design	Proper determination of site stratigraphy and hydrogeology, re-evaluation of modeling/design basis and determination of well yields
	Well Design	Inappropriate design including Incorrect drilling methods well/screened interval, materials, pump type or size	Re-evaluation of design parameters
	Insufficient Development	Poor development leading to silting of well and blockage of filter pack and screen	Redevelop wells using procedures appropriate for aquifer and well
	Pump Too Small/Wrong Pump Type	Pumps operating at rated capacity but not producing expected amount of water	Install larger pumps or change to pump type that can produce the required amount of water; install additional wells; check the proper pump control settings
	Pump Too Large/Wrong Pump Type	Pumps producing more water than aquifer can yield causing excessive cycling and cause siltation	Install smaller/lower flow pumps; or lower pump rate and/or trim the impellers
	Physical Damage/Blockage	Well/pump damaged during installation, discharge line kinked or blocked with construction, debris	Inspect pumps and discharge piping for leaks/damage/blockage; determine if screen/well is physically blocked
	Incorrect Pump Control and Intake Settings	The pump intake or low level control is not placed deep enough in the well to take advantage of available drawdown.	Reset the pump intake or low level control to a greater depth.

TABLE 2-2 (Cont'd)

Extraction Unit Troubleshooting

Symptom	Problem	Description	Solution
Water Yield Decreasing Over Time	Mineral Encrustation	Well screens, pump inlets, level controllers, discharge piping blocked with mineral encrustation	Treat system with appropriate acid treatment on a periodic basis as part of maintenance program, redevelop well using jetting methods, re-evaluate well design/pump placement based upon geochemistry
	Biological Fouling	System components blocked with biological mat	Treat system with appropriate biocide as part of periodic maintenance, evaluate installation of permanent well disinfection systems, re-evaluate well design/pump placement
	Siltation	Well accumulating silt leading to less available screen area and/or erosion of pump impellers	Redevelop well as necessary
	Weather	Drought conditions causing lowering of water table	Lower pump, temporarily shut down system
	Incompatible well/pump components	Well/pump materials affected by ground water or contaminants leading to blockage or physical damage	Replace affected components, change pump type, install new wells using appropriate materials
	Well Spacing	Recovery wells located too close together; capture zones too large	Install well level controllers to limit drawdown, trim impeller/install smaller pumps or decrease number of pumping wells
Low Contaminant Mass Removal	Poor Characterization	Wells missed plume, wells screened at wrong depth or pumps placed at wrong depth to capture NAPL	Adjust pump depths, convert well to other use (water level, monitor wells), install new wells

TABLE 2-2 (Cont'd)

Extraction Unit Troubleshooting

Symptom	Problem	Description	Solution
Low Contaminant Mass Removal (continued)	Poor Design	Pumps/recovery system inappropriate for contaminants	Re-evaluate design based upon new data, install new wells
	Too Little Drawdown	Capture zone smaller than anticipated resulting in less water/NAPL removal	Move pump/level controllers, change pump size/type
	Tidal/Weather	Tidal fluctuations causing water/LNAPL levels to rise above/below screen, drought,/flooding affecting water level	Adjust pump depths, temporarily shut down system
Excess Water Production	Poor Characterization and/or Design	NAPL recovery well producing more water than expected	Adjust pump depths, change pump type, re-evaluate design based upon current information
Inadequate Plume Capture	Poor Characterization and/or Design	Capture plumes not as large as planned	Re-evaluate design based upon current information
	Pumps Too Small	Pumps cannot remove sufficient water to establish planned capture zone	Install larger/different type of pumps, re-evaluate design
	Pumps Too Large	Excessive cycling of pumps prevents establishment of capture zone or causes excessive pump failures	Install smaller/different type of pumps, re-evaluate design
	Well Placement or Spacing	Poor well placement and/or spacing prevents establishment of adequate capture plume	Re-evaluate wells, install additional wells
	Plume Movement During Regulatory Approval or Construction Phase	Plume continues to move during regulatory review or during system construction and startup	Re-evaluate system design based upon current plume location, install additional wells, increase flow from existing wells
High Contaminant Loading	Poor Characterization	NAPL, higher contaminant concentrations identified during system installation	Re-evaluate design, modify system to handle high contaminant loads, limit recovery system to balance contaminant loads

TABLE 2-3

Transport Unit Troubleshooting

Symptom	Problem	Description	Solution
Air/Water Line Low or No Flow	Encrustation/Fouling	Discharge and/or injection lines plugging, pneumatic air lines plugging	Soften water/biological treatment systems where appropriate, chemically treat lines as part of periodic well maintenance, install filters, dryers on air system, construct lines out of materials appropriate for use.
	Sedimentation	Slow flow rates allow accumulation of sediment in discharge lines	Design appropriate system based upon expected flow velocities, install filters and clean out ports, install crossovers to allow lines to be blown out with compressed air
	Poor Design	Length, size, number of turns/valves increase likelihood for sedimentation and encrustation, system components incompatible with contaminants, air locks in piping can cause plugging	Evaluate design and location of equipment, install filters/chemical treatment systems, install system with compatible components, design piping with air release valves.
	Construction Debris	Construction debris remaining in system prevents effective operation	Clean and water flush lines prior to final assembly
	Weather	Lines freezing during cold weather; lines expanding, crackling or dislocating due to expansion during warm weather	Appropriate design based upon expected weather conditions, install lines below grade, insulate and heat-trace lines for freeze protection and/or expansion loops as necessary

TABLE 2-4

Injection Unit Troubleshooting

Symptom	Problem	Description	Solution
Low Injection Rates	Poor Characterization	Incorrect characterization leading to aquifer not taking sufficient water	Proper determination of well yield
	Poor Design	Wells/injection system design limits amount of water that can be injected	Proper design based upon good characterization; evaluate design and modify system
	Inadequate Injection Capacity	Insufficient number of injection wells to handle quantity of water produced	Install additional wells, limit water recovery, modify well design, consider infiltration basins and injection trenches when adding injection capacity.
Falling Injection Rates	Encrustation/Fouling	Mineral encrustation and/or biological fouling plugging injection wells and piping	Rehabilitate wells with appropriate chemicals; soften water/biological treatment systems; select appropriate materials of construction
	Treatment System Nutrients/Additives Reacting with Aquifer	Additives added during treatment reacting with aquifer material and causing excessive fouling/mineral precipitation	Evaluate additive quantities and injection locations, change additive types
	Sedimentation	Slow flow rates allow accumulation of sediment in discharge lines	Design appropriate system based upon expected flow velocities, install filters and clean out ports, install crossovers to allow lines to be blown out with compressed air

TABLE 2-4 (Cont'd)

Injection Unit Troubleshooting

Symptom	Problem	Description	Solution
Falling Injection Rates (continued)	Poor Design	Length, size, number of turns/valves increase likelihood of sedimentation and encrustation, system components incompatible with contaminants	Evaluate design and location of equipment, install filters/chemical treatment systems, install compatible components
Injection Pushing Plume in Wrong Direction	Poor Characterization	Location of injection wells pushing plume away from recovery wells	Install additional injection wells in more appropriate locations, evaluate amount of water being injected in each well
	Water Balance	Some wells taking more water than others causing the plume location to shift	Install additional injection wells in more appropriate locations, evaluate amount of water being injected at well locations
Mounding/Flooding	Poor Characterization and Design	Aquifer not able to handle the amount of water to be injected	Install more wells, evaluate depths and well materials, limit amount of water to wells and infiltration galleries, evaluate other discharge options
	Encrustation/Fouling	Fouling of wells limiting the amount of water that can be injected; fouling of level controls allowing overflows	Chemical treatment of water prior to injection
	Operation and Maintenance Problems	Damage and deterioration of system components allowing excessive injection rates	Evaluate O & M program, perform periodic maintenance

Figure 2-2
Troubleshooting Flow Chart
Low Initial Water Extraction Rate
Sheet 1/3

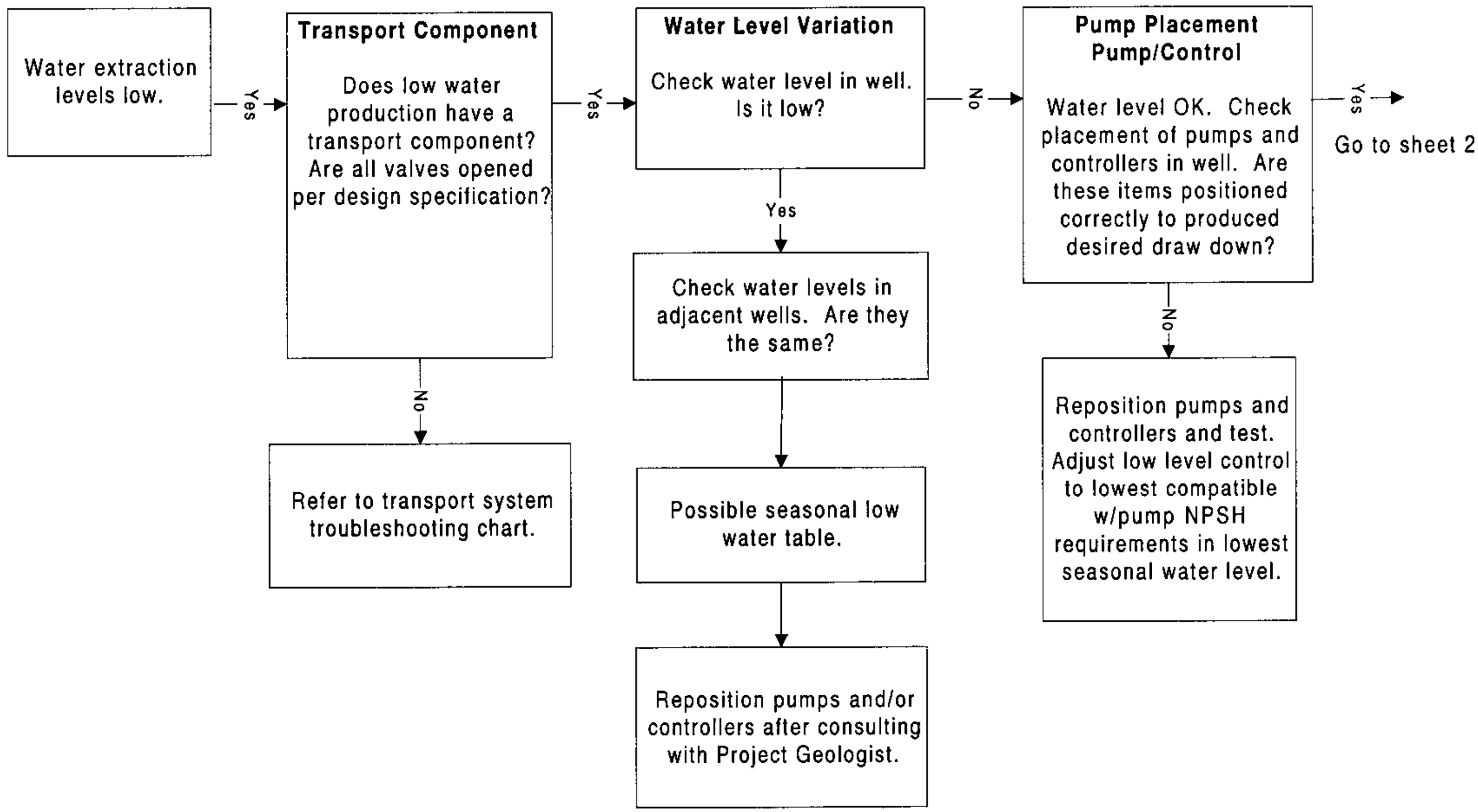

Figure 2-2
Troubleshooting Flow Chart
Low Initial Water Extraction Rate
Sheet 2/3

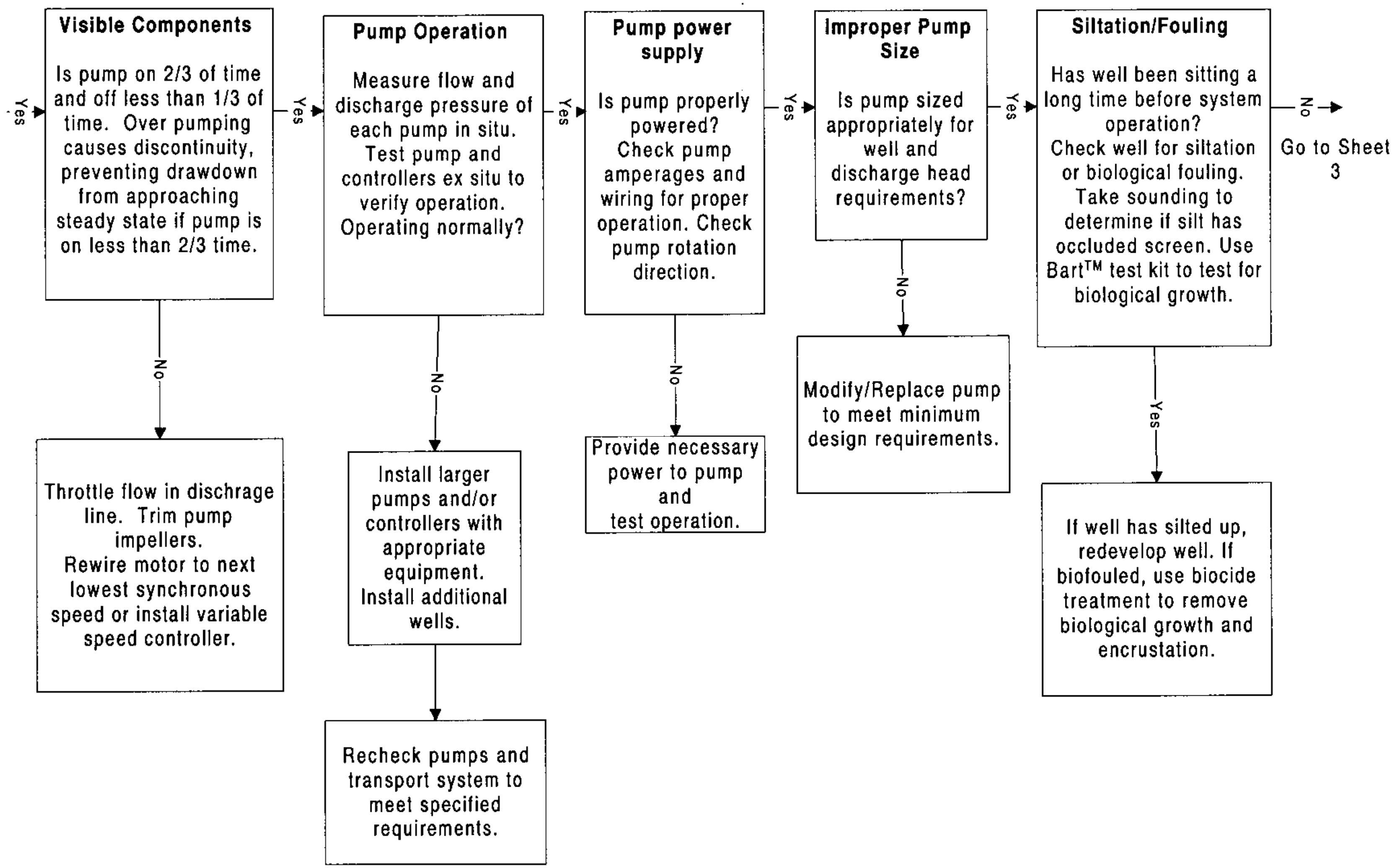

Figure 2-2
Troubleshooting Flow Chart
Low Initial Water Extraction Rate
Sheet 3/3

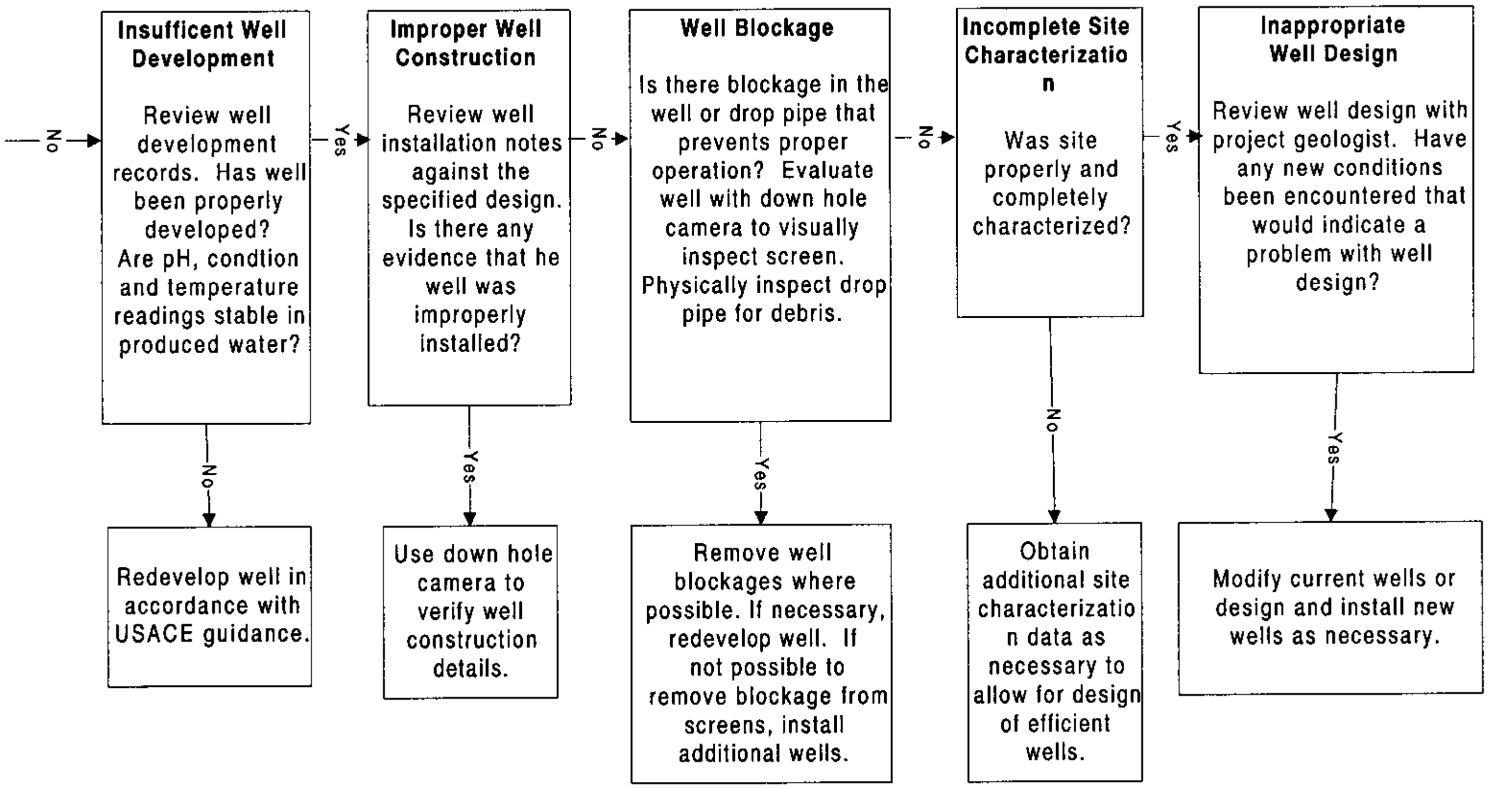

Figure 2-3
Troubleshooting Flow Chart
Water Extraction Rate Declining Over Time
Sheet 1/2

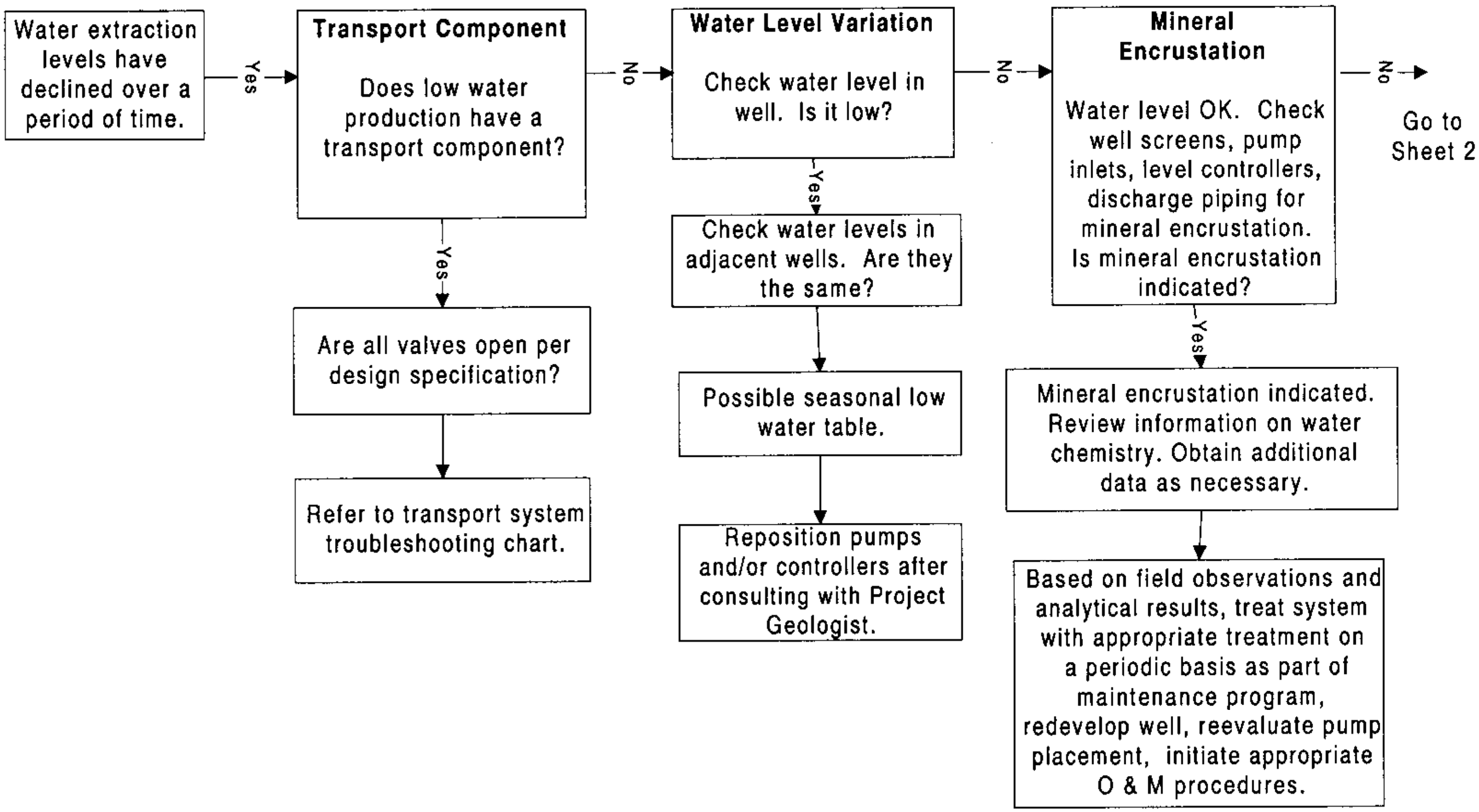

Figure 2-3
Troubleshooting Flow Chart
Water Extraction Rate Declining Over Time
Sheet 2/2

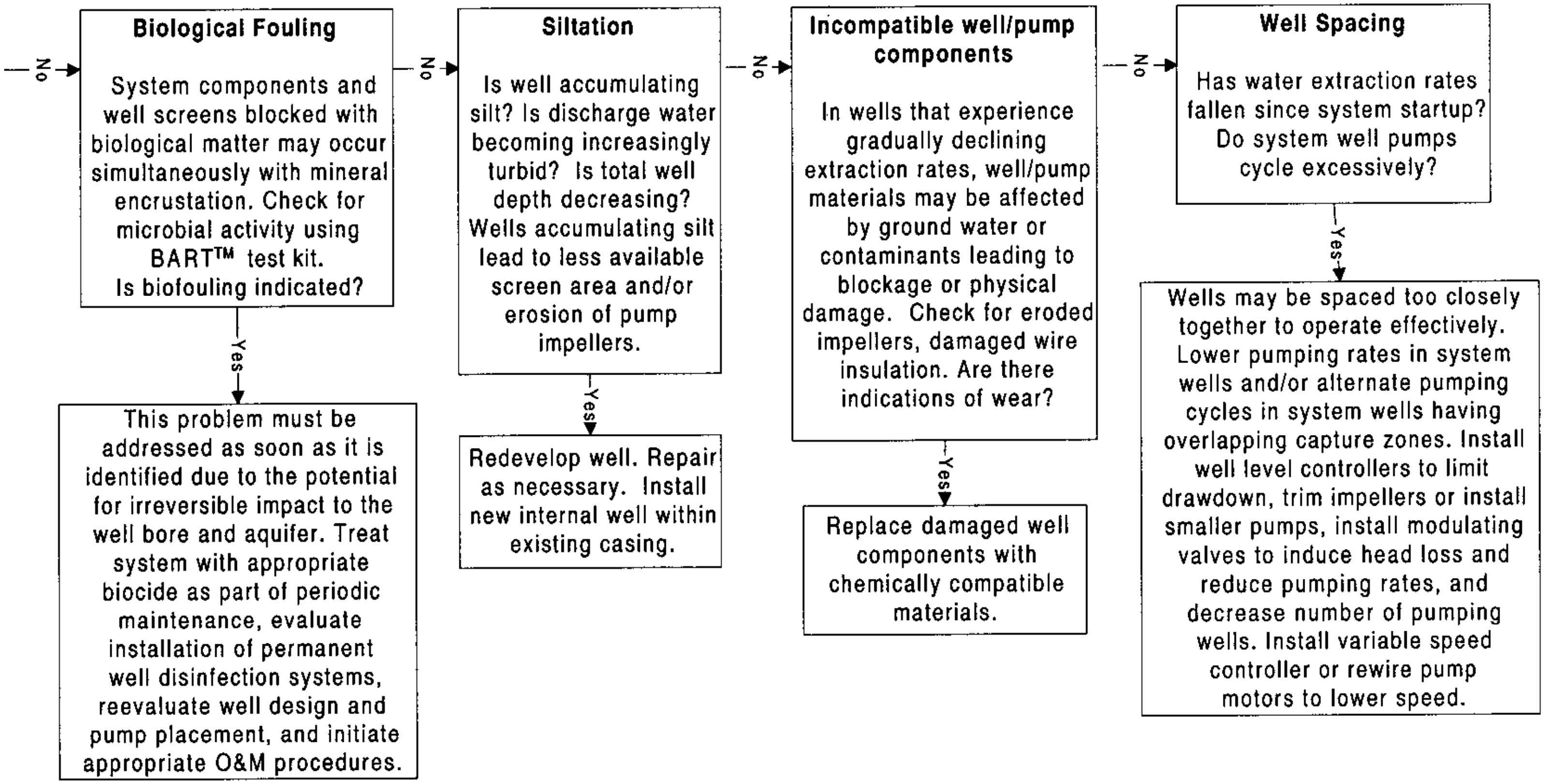

Figure 2-4
Troubleshooting Chart - Extraction Unit
Low LNAPL Removal Rates
Sheet 1/2

LNAPL recovery is less than system design.

Yes →

Insufficient or Excessive Water Table Drawdown

Is the drawdown in the extraction wells outside design specifications? Is the ratio of water extraction to product extraction changing? Inadequate drawdown may prevent adequate volumes of LNAPL from entering the extraction well or trench. Excessive drawdown may smear LNAPL vertically across dewatered soils and convert free flowing phase to relatively immobile phase which is difficult to recover. In addition, excessive drawdown may be accompanied by high water production rates.

No →

Excess Water Production

Is NAPL recovery well producing more water than expected?

No →

Go to Sheet 2

Yes ↓

Adjust pump depths, change pump type, check for pumps causing emulsification & re-evaluate design based upon current information.

Yes ↓ (from Insufficient or Excessive Water Table Drawdown)

May be caused by inappropriately sized pumps or incorrectly placed level controllers, inappropriately spaced wells, or inappropriately operated wells.

↓

Move pump/level controllers, change pump size/type to carefully control draw down and maintain it within specified range. If wells are spaced too closely together, consider a phased pumping program or cycling extraction. Install variable speed controllers, trim impellers, rewire pump motors to lower speed.

Figure 2-4
Troubleshooting Chart - Extraction Unit
Low LNAPL Removal Rates
Sheet 2/2

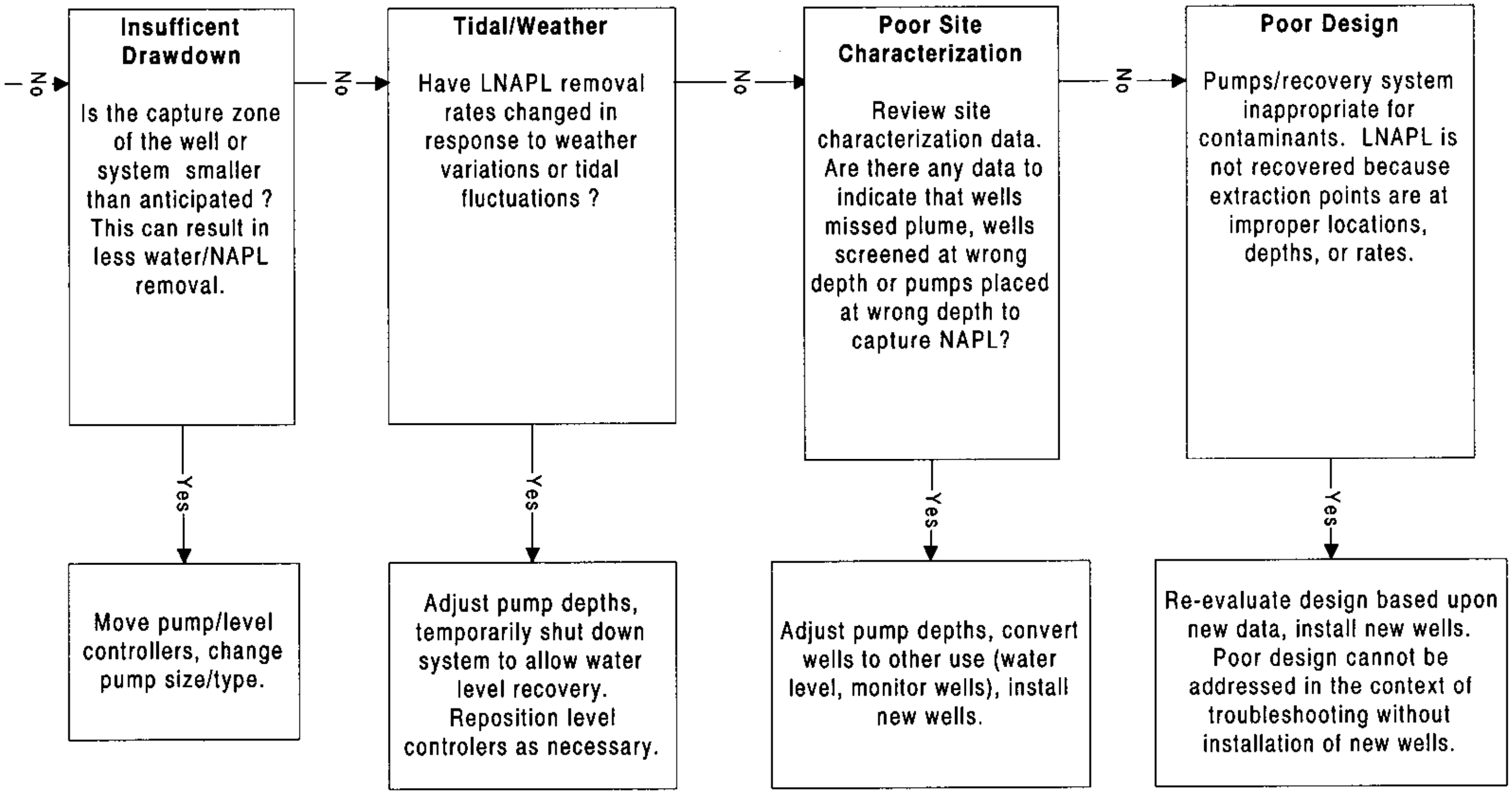

Figure 2-5
Troubleshooting Flow Chart
Extraction System / Inadequate Plume Capture

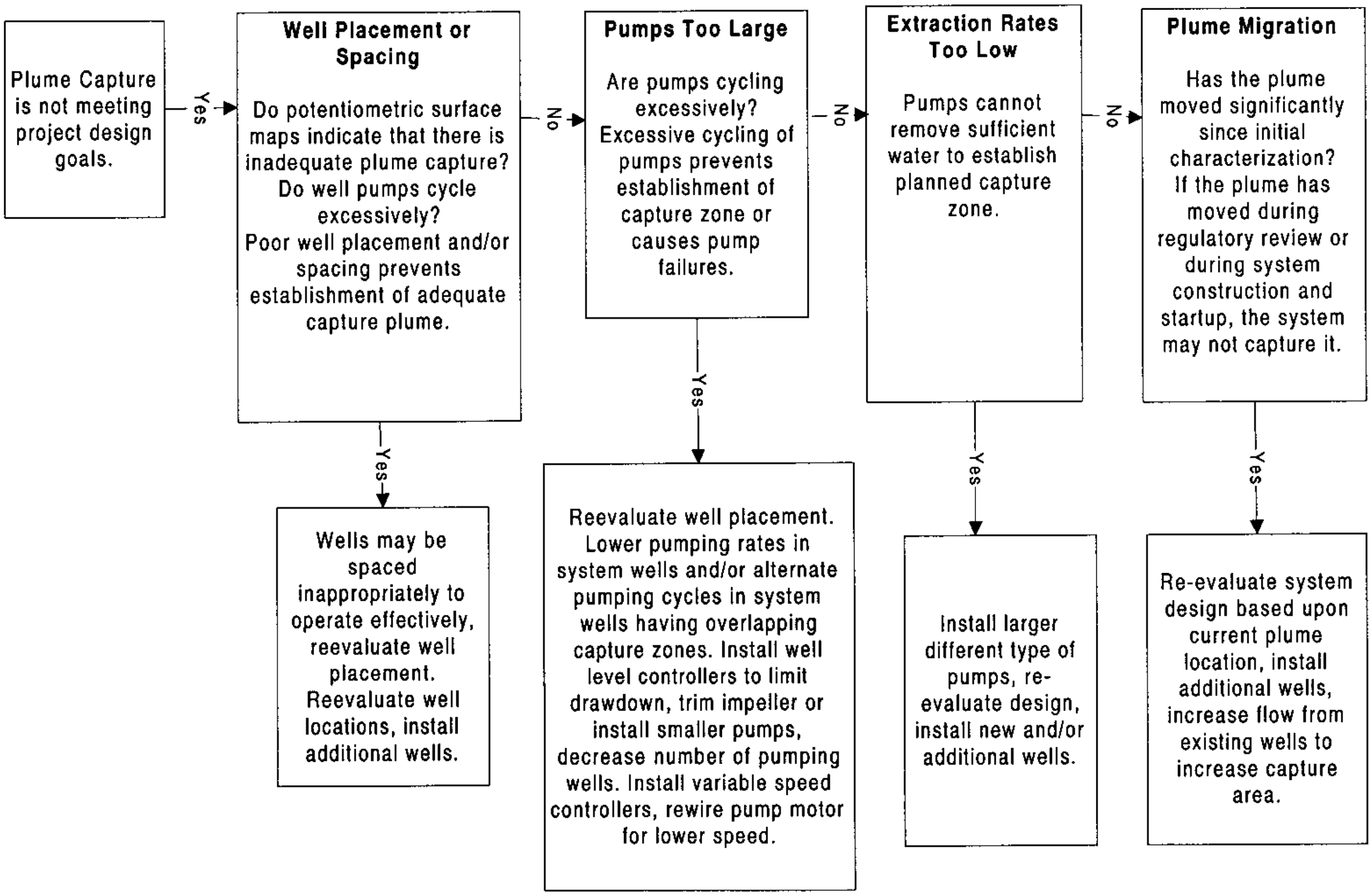

Figure 2-6
Transport Unit Troubleshooting
Sheet 1/3

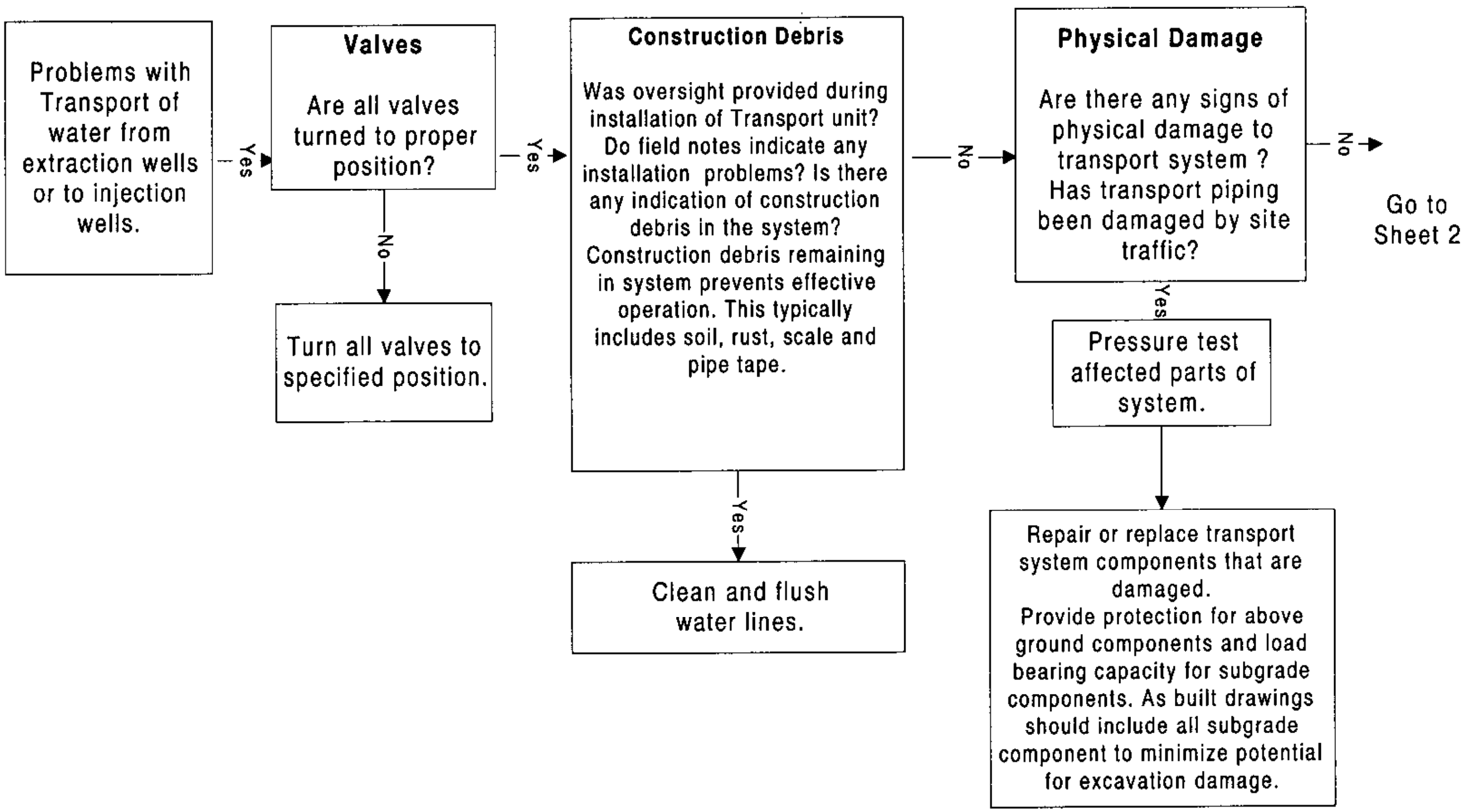

Figure 2-6
Transport Unit Troubleshooting
Sheet 2/3

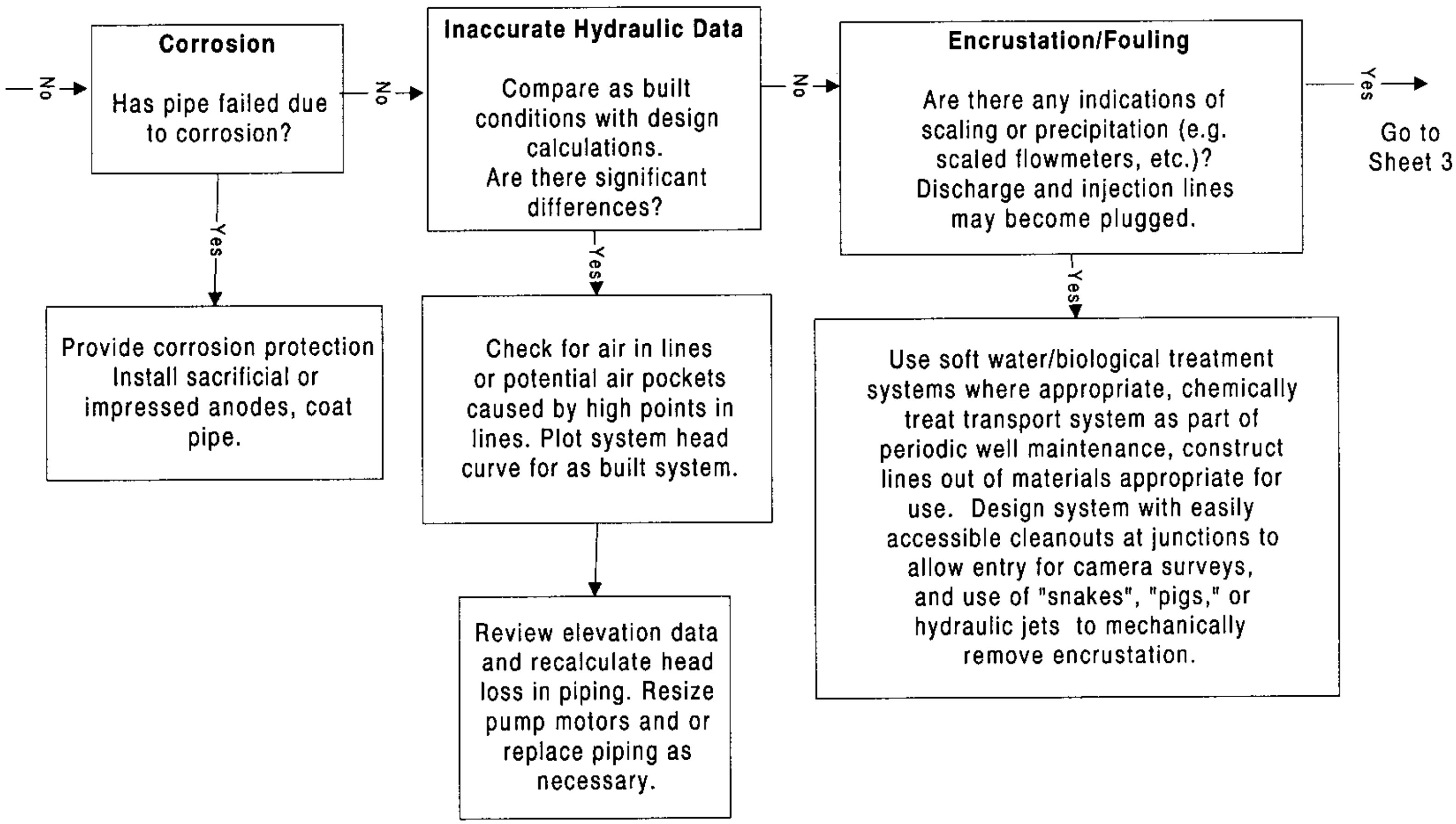

Figure 2-6
Transport Unit Troubleshooting
Sheet 3/3

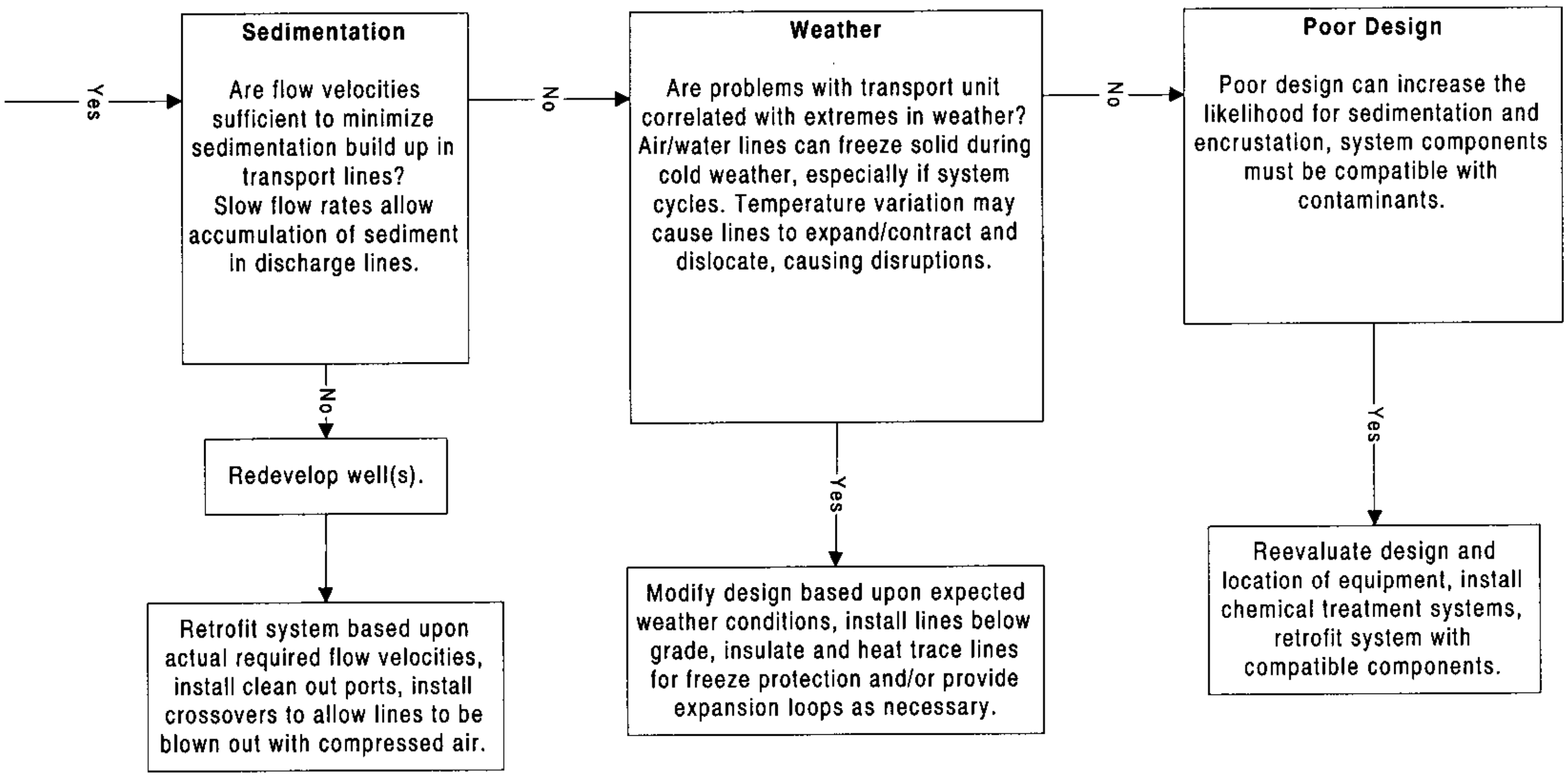

Figure 2-7
Injection Unit Troubleshooting
Low Initial Injection Rates
Sheet 1/3

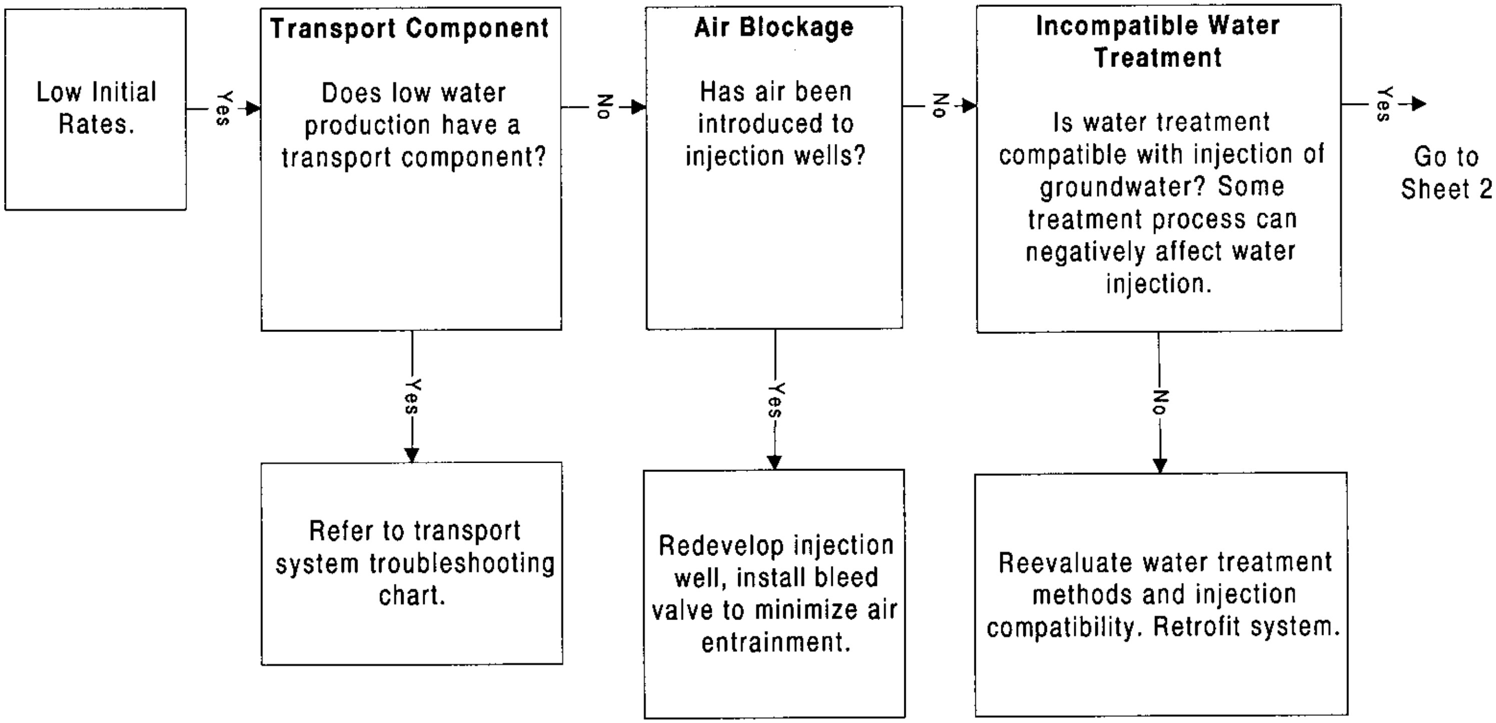

Figure 2-7
Injection Unit Troubleshooting
Low Initial Injection Rates
Sheet 2/3

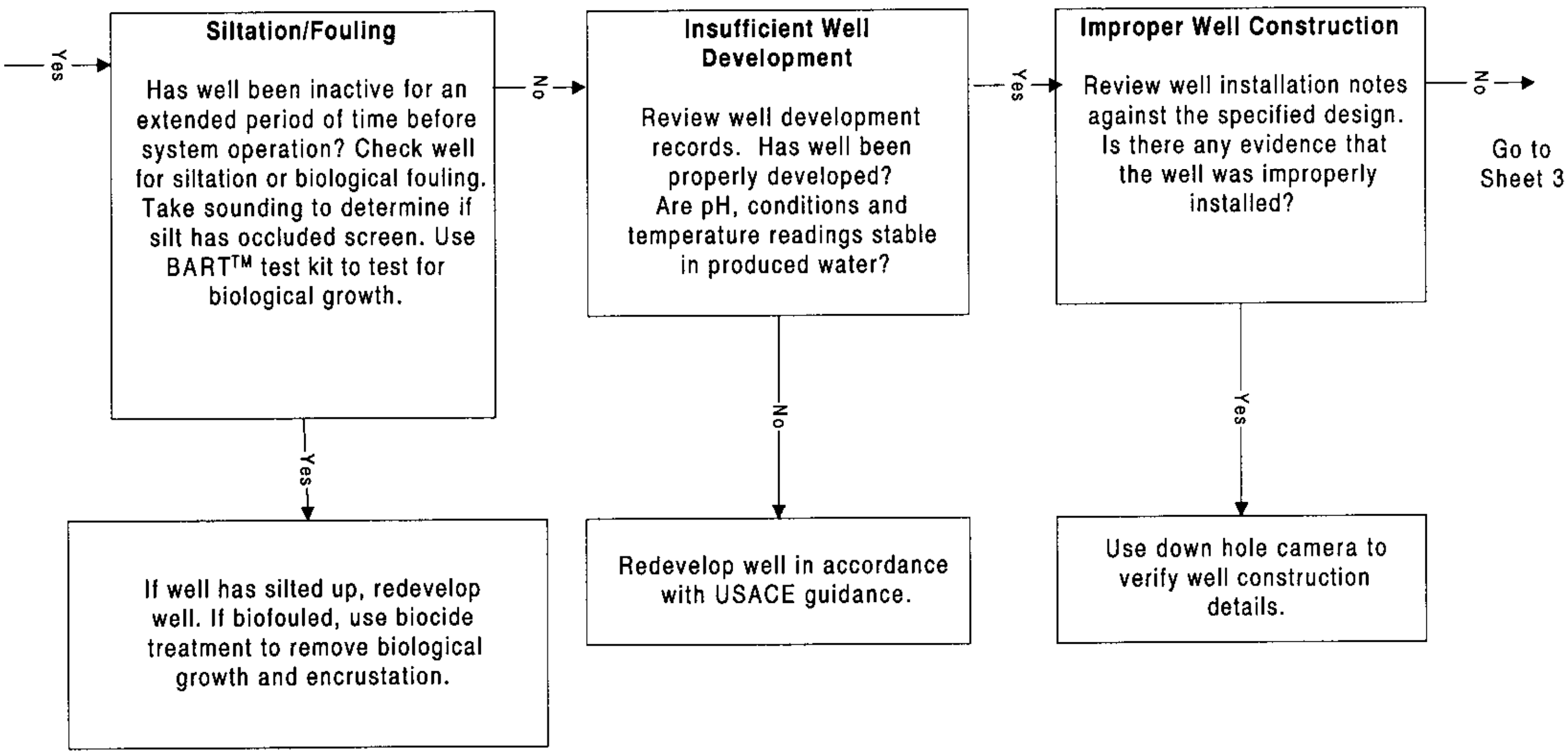

Figure 2-7
Injection Unit Troubleshooting
Low Initial Injection Rates
Sheet 3/3

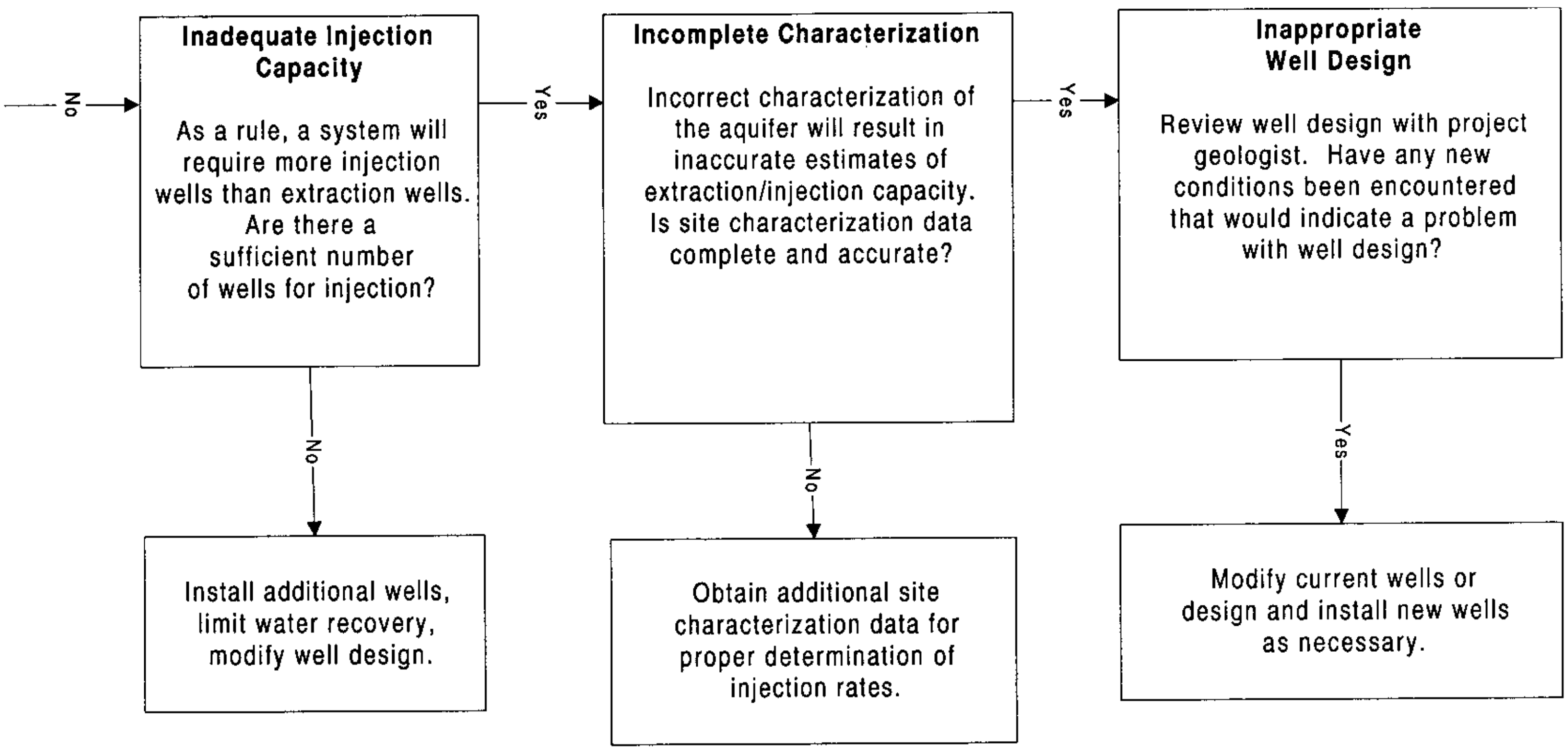

Figure 2-8
Troubleshooting Flow Chart
Injection Rate Declining Over Time
Sheet 1/2

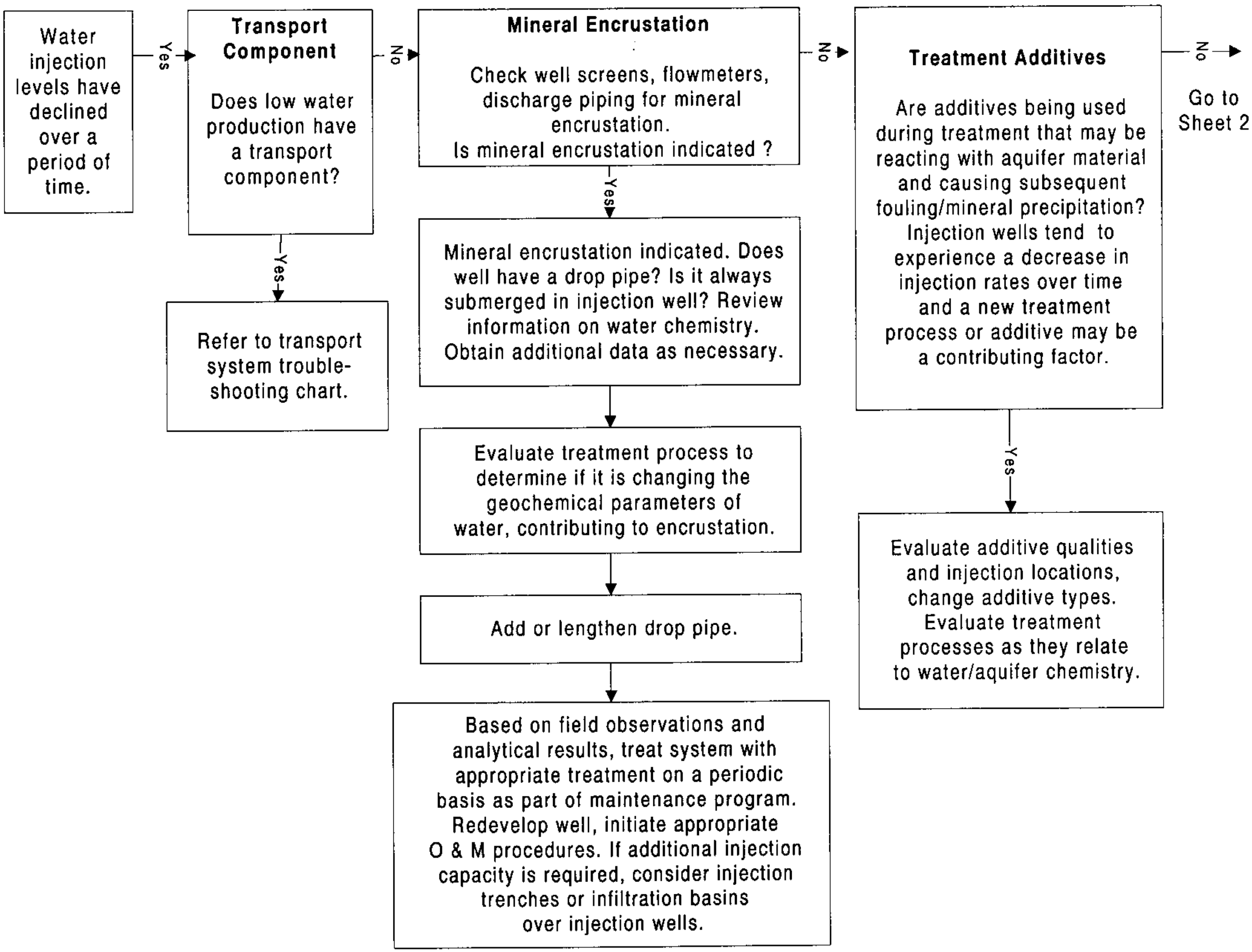

Figure 2-8
Troubleshooting Flow Chart
Injection Rate Declining Over Time
Sheet 2/2

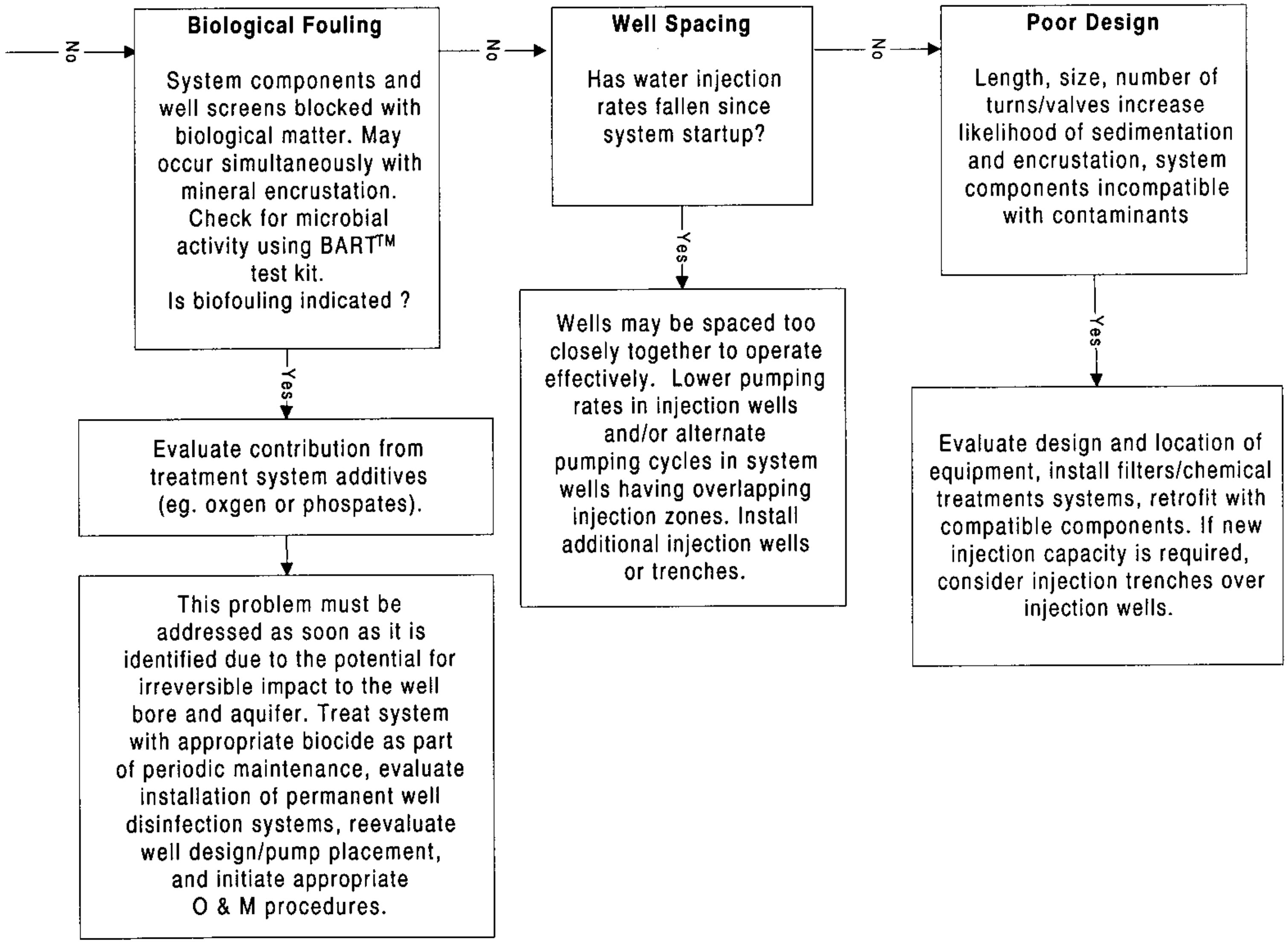

Figure 2-9
Injection Unit Troubleshooting
Injection Altering Plume Direction

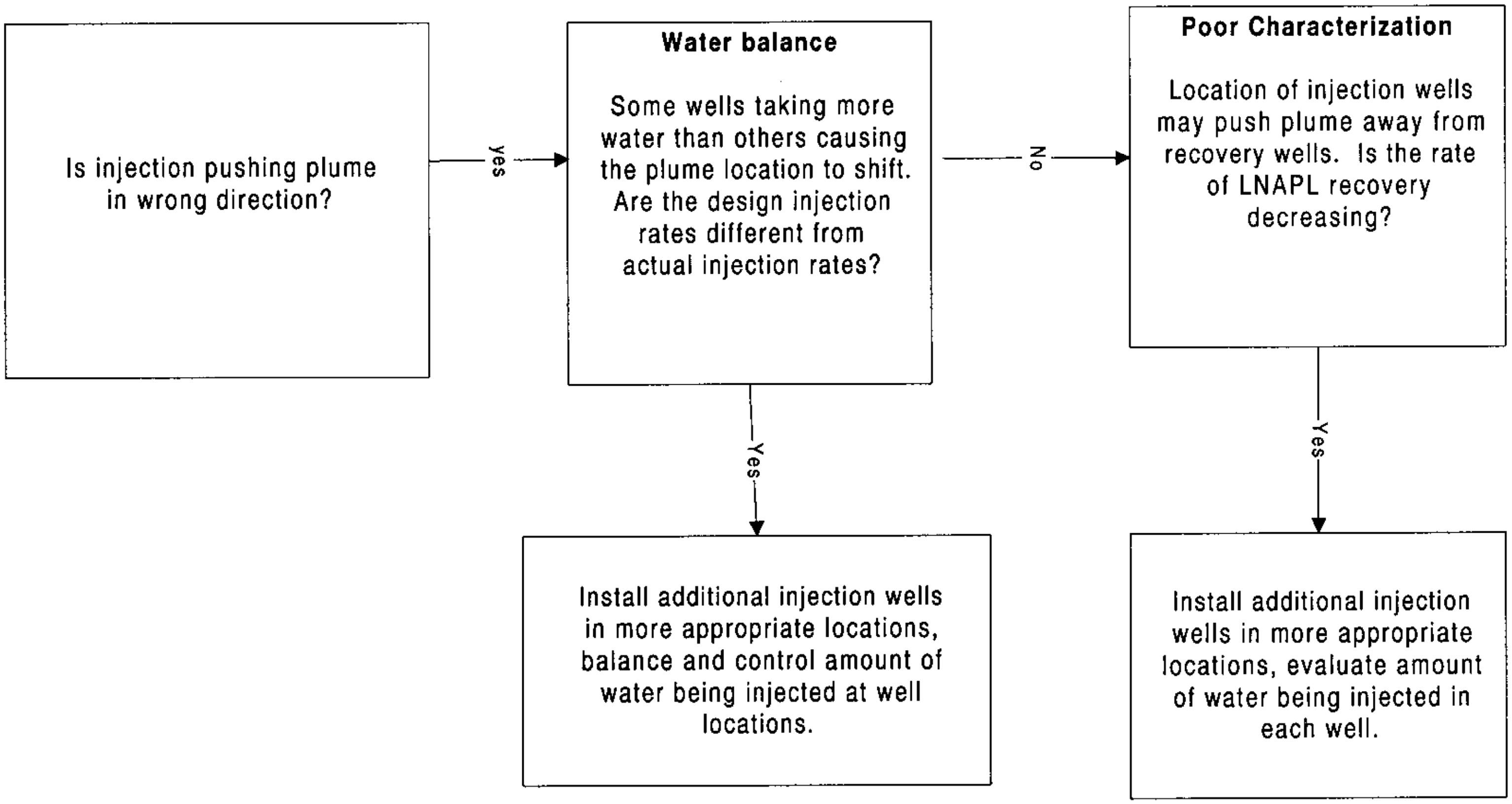

Figure 2-10
Injection Unit Troubleshooting
Mounding/Flooding
Sheet 1/2

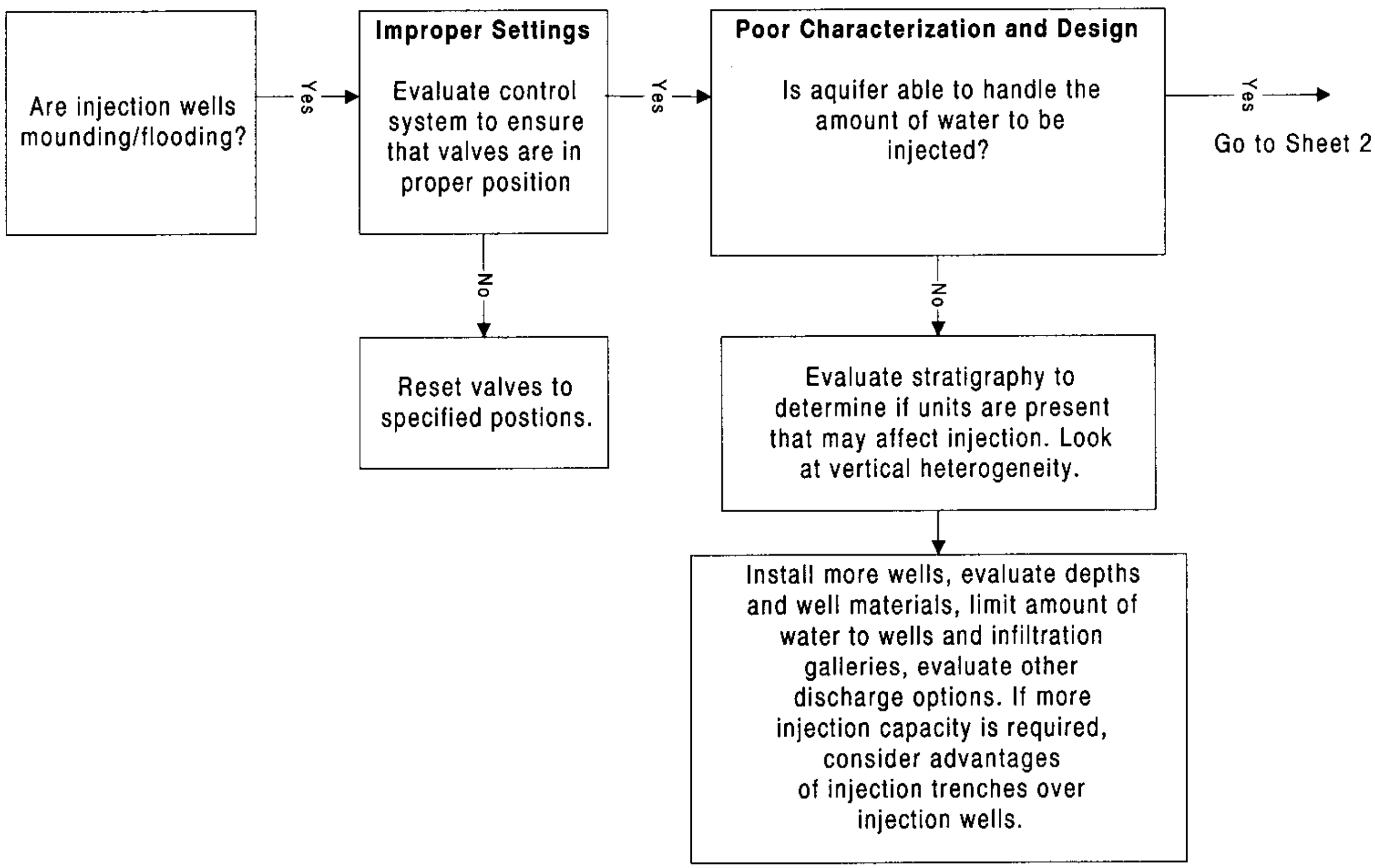

Figure 2-10
Injection Unit Troubleshooting
Mounding/Flooding
Sheet 2/2